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INDUSTRIAL — SCIENTIFIC

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Devoted to Measurement and Control Problems

Vol. 3. No. 9 Pittsburgh, Pa. September, 1930

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Analyzer for Sound Picture Installations
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New Three Position Pilot Switch

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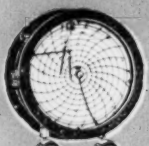

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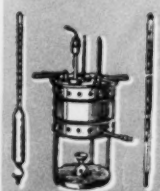

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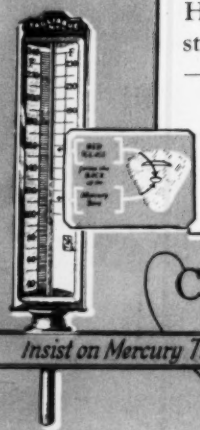

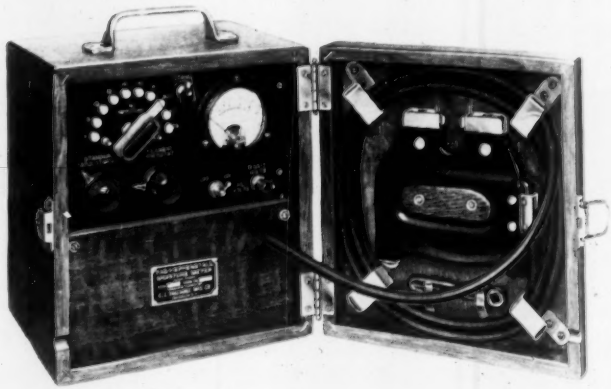

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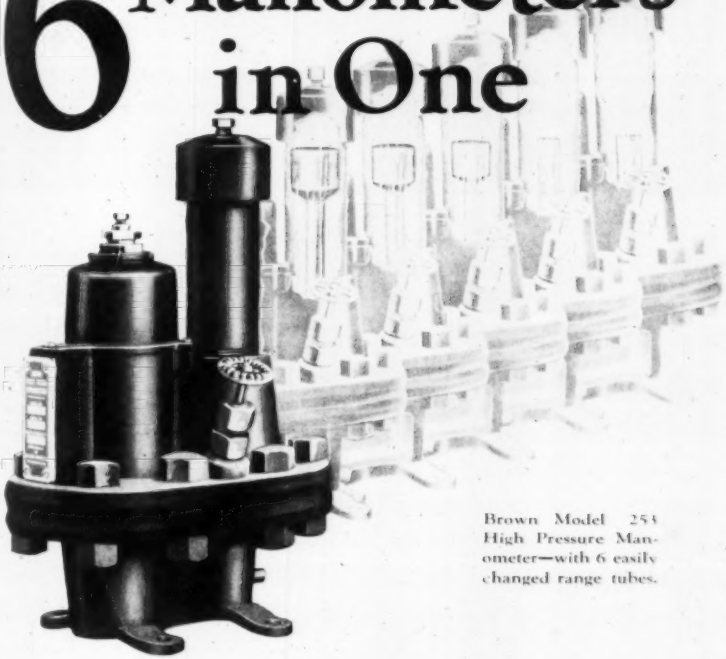

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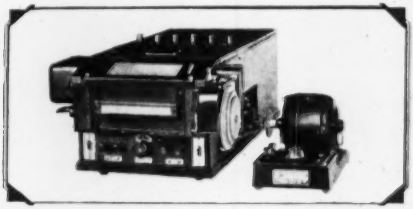

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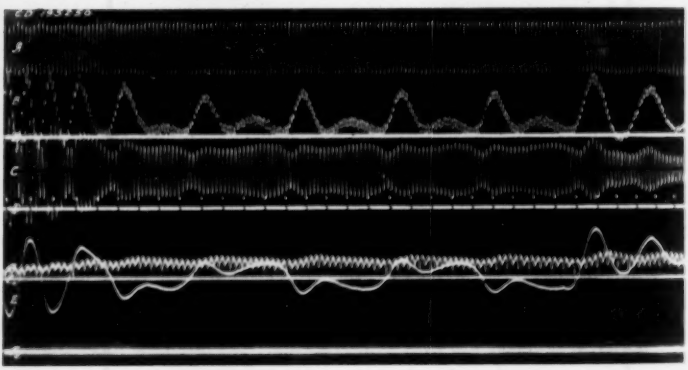

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610-47D

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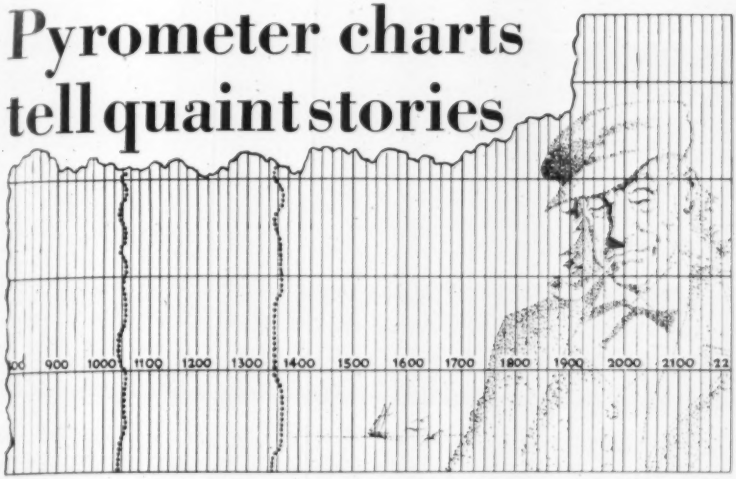
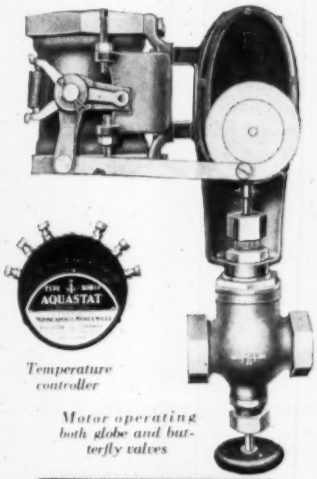


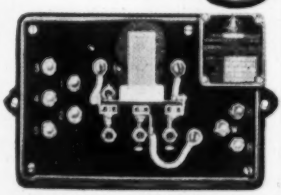
Like a tale of the sea, a pyrometer chart, with its waves and billows, gives a graphic account of mountainous seas, lashed by erratic hand control. Yet the same chart may record "smooth sailing" where furnace, oven or kiln controls include Minneapolis-Honeywell apparatus.

Motorized units include both fuel and air valves and apply where either oil or gas is used as the source of heat. There are also pressure and temperature controllers, while, in high temperature furnaces, installations are made in conjunction with any standard pyrometric controller.



Temperature controller

Motor operating both globe and butterfly valves



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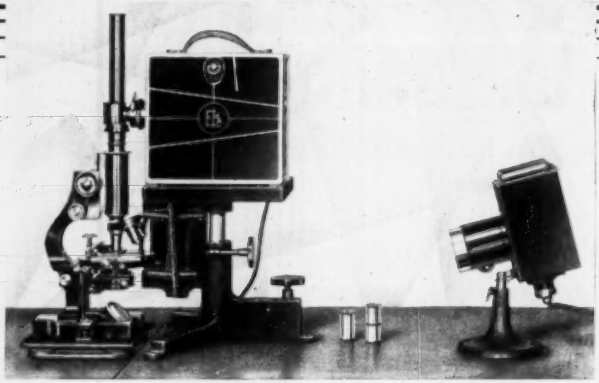

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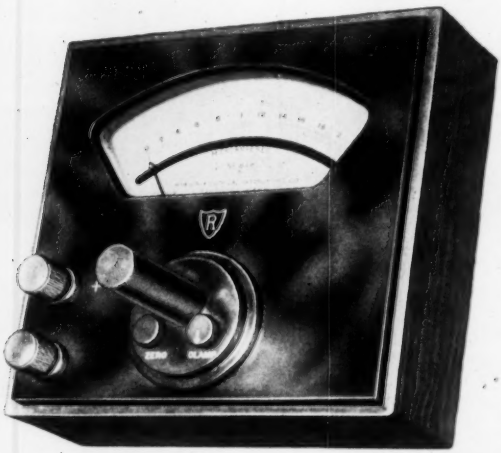

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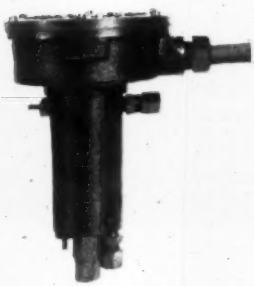

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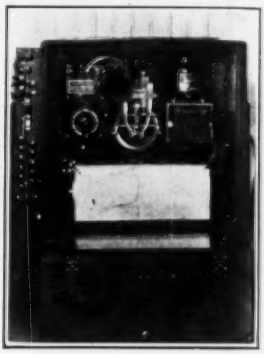

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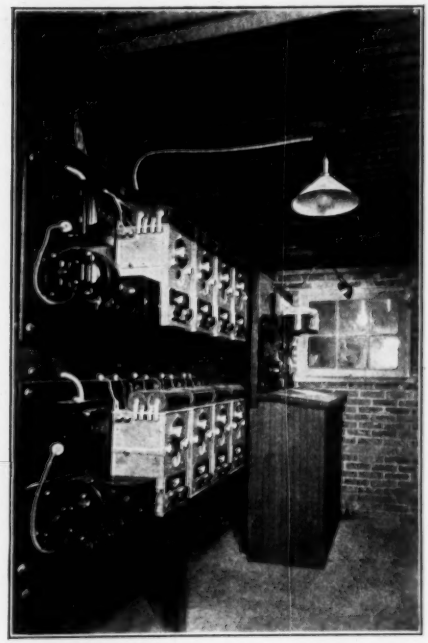

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Vol. 3, No. 9 SEPTEMBER, 1930 Pittsburgh, Pa.

To Our Readers

WE would urge our readers to fill out the Metric Poll Ballot and return it to us at the earliest opportunity.

Due to the importance of the recent revision of "Experimental Mechanical Engineering" in the literature of measurement technology we give the review of this book here.

EXPERIMENTAL MECHANICAL ENGINEERING, VOLUME I, ENGINEERING INSTRUMENTS. *Herman Diederichs & William C. Andrae.* John Wiley & Sons, Inc., New York, 1930. Cloth, 6 x 9 inches, 1082 pages. Price $8.00 Postpaid.

This is a thick tome of 1082 pages —which length alone entitles it to a place of importance in the literature of measurement technology, and gives an idea of the formidable amount of labor involved in its preparation. Though the learned authors modestly state that this work is a revision of the seventh edition of "Experimental Engineering" by Professors Carpenter and Diederichs, even a "mere" revision of a thousand-page scientific work is heartbreaking drudgery. But this achievement is much more than a mere revision.

Onerous, therefore, to the undersigned in particular, is the duty of impartially reviewing this monument to the patience, self-sacrifice and erudition of two respected teachers. If the two present reviewers themselves dwelt in cloistered academic halls by the shore of a crystal lake far from contacts with practicing engineers, they would hold views making their duty most pleasant. Unfortunately both reviewers live and work in Pittsburgh, daily rub shoulders with practicing engineers, constantly come in contact with instrument-makers and -users, and cater to a "public" to whom instruments must be practical means to economic ends. Onerous, therefore, to the two present reviewers who many years ago swapped their rose-tinted spectacles for the merciless microscope of the great god Efficiency.

And yet both reviewers, in spite of hard-boiled "professionalism" inevitably acquired through years of engineering work with engineering instruments for engineering purposes, unhesitatingly acclaim this "amateur" theoretical book as a magnificent contribution to industrial progress. Every addition to the literature of instrument technology is of value to our industrial civilization. Some additions are bulky but of small value, as the new issue of a manufacturers' general catalog; some additions are brief but great in value, as the announcement of a new principle of instrumental measurement or of a new labor-saving instrument. Some additions are of direct value, as a practical manual; and some, finally, of indirect value. Among these last come students' text books, reference works and theoretical dissertations on physical and chemical properties which underlie the principles and methods of instrumental measurements. "Experimental Engineering" defies analysis and classification along the above lines: It is primarily a scientific reference work, but here and there one comes across refreshing bits of "real practical dope." Not only is it a priceless reference work for the student but it is a "good buy," worth $8 of a working engineer's money.

Such is the reviewers' conclusion, but it was not reached until the twentieth or thirtieth hour of their critical study of the book. A week ago, when we sat down with the book between us and began to thumb its pages, our first impression was that 99% of the illustrations were of long-obsolete instruments —and there is no doubt that this very obvious imperfection will spoil many a bookstore sale to many a practicing engineer. Of course the proportion of old-model figures is far from 99% but it is lamentably high. Instruments are pictured which were superseded not last year but five, ten, fifteen or more years ago, as for instance (in the temperature chapter alone) the Féry and the Wanner optical pyrometers, the Féry bimetallic radiation pyrometer, and most of the industrial pressure-spring indicating and recording thermometers. It would be too much to expect of two university professors, busy with many important duties, to correspond with all instrument manufacturers (nearly 500) as the reviewers do in the course of their business, in order to obtain illustrations of late models, but it seems a pity that the authors did not succeed in getting the latest illustrations from the ten or twelve largest instrument manufacturers whose products constitute (as a rough guess) 25% of the instrument illustrations.

To lack of contact with instrument-makers must also be attributed inaccurate descriptions of instruments. Example: "The recorders of the [A] Company and of the [B] Company are so similar to the [C] recorders that no further description is necessary." This assertion drew an angry denial from a research engineer on the staff of the "B" Company.

As the foregoing quotation would indicate, *recording* instruments (except under fluid volume and flow measurement) are given scanty treatment in comparison with such indicating instruments as are discussed —which is natural

in a reference work on the scientific laws and principles of measurement—but controlling instruments are left out altogether. In view of the ever-growing importance of automatic control of temperature, fluid flow, humidity, pressure, level, and other conditions and properties, it seems to the reviewers that even a reference work should have included discussions of at least the basic scientific principles of automatic control, at the end of each chapter. But evidently this was definitely out of the authors' scope, and therefore no fault is implied in bringing up this point.

Inadequacy of instrument illustrations and descriptions characterizes many headings. Under "Humidity" there are shown only two illustrations: a diagram of one dew-point apparatus and a cut of a "U. S. Weather Bureau" sling psychrometer. Outside of brief references to these two instruments not a word about other humidity indicating, recording and controlling instruments! Oh yes, one little footnote, which may be quoted verbatim:

> "Instruments are on the market for continuously recording relative humidity. Thus the Bristol Co., Waterbury, Conn., make a Wet and Dry Bulb Recorder, and Leeds & Northrup make a Relative Humidity Recorder which is described by L. Behr in a paper in the Journal of the Optical Society of America, Vol. 12, No. 6, 1916."

—a sketchy treatment which is worse than would have been the entire omission of the subject of humidity measurement from the scope of the book.

Gleefully pointing out inconsequential gaps in printed lists usually stamps a book reviewer as a peanut-wooled smart-aleck. We therefore shall pass by all such trifling omissions and stick to some of the significant ones—to some omissions of classes and types from instrument classifications:

Under smoke recorders on page 886 the application of the photoelectric cell to smoke recording is omitted. (That of Westinghouse Electric & Mfg. Co. was described in *Instruments*, March 1930, page 203, that of General Electric Company in May 1930, page 339.)

Under fuel calorimeters (47 pages) the Burgess-Parr recording gas calorimeter, and the Thomas Calorimeter (Cutler-Hammer, Inc.) are omitted. (*Instruments*, February 1930, pages 87-101.)

In the 115-page chapter on engine indicators, we found no mention of the electrical engine indicator of Martin & Caris using the McCollum-Peters electric telemeter for pressure measurement. (Described in *Instruments*, Sept. 1929, page 319) Nor the Geiger Pimeter for the measurement of mean indicated pressure.

On page 844 a list of manufacturers of electric CO_2 meters is given but the name of Chas. Engelhard, Inc. is omitted. The primary element of the Engelhard CO_2 recorder is of a distinct type.

Under planimeters appear several adequate descriptions mostly of polar planimeters but no mention of square root planimeters, nor integrators for flowmeter charts which average simultaneous product of square root of differential times absolute static pressure, nor of planimeters for round charts in which the chart center is moved while the measuring wheel remains in one position.

So much for omissions from "catalogs" of types of instruments. More serious are omissions of classes or types which the book flatly declares do not exist. Example, page 960: "As yet no means has been devised for measuring oiliness." The Herschel Oiliness Machine, developed at the Bureau of Standards about a year ago, is described in *Instruments*, September 1930, page 599.

Two other classes of instruments, both of considerable value to engineers, are omitted. One is the class of instruments for the measurement of the effectiveness of heat insulation materials. (One type was developed by Dr. Nichols at the Pittsburgh Station of the Bureau of Mines; another is manufactured by the Weston Electrical Instrument Corporation, described in *Instruments*, January 1930, page 59.) The other class of instrument is for the measurement of vibration in machinery, of which there are a number on the market. (*Instruments*, Feb. 1929, page 71; March 1929, page 103.)

Although the preface is dated May 15, 1930, it may reasonably be supposed that the indefatigable authors worked without a large staff of assistants and therefore could not bring the entire book up to date. This would account for the illustrations of obsolete instruments, the assertion that no means of measuring oiliness has been devised, and so on. Indeed it would be a superhuman task for any two busy professors to make any thousand-page reference work represent the "state of the art" up to, say, six months before its publication.

Of the highest excellence are all of the theoretical portions of the book, including those at the start of the six (out of eighteen) chapters entitled "Measurement of . . . ." Most of these theoretical portions of the volume are painstaking compilations; some also gladden the heart of the reader by reason of the addition of valuable original matter written by the authors. Examples in Chapter I alone: Art. 5 (The Measurement of Fluctuating Quantities); Art. 8 (Most Probable Value of a Series of Observations); Art. 13 (Graphical Representation of Experimental Results and the Determination of Empirical Equations from the Graphs).

Most chapters, necessarily, deal with the theory of measurement and hardly with practical instrumental measurement. For example, Chapter VIII, Properties of Gases and Vapors, runs to 72 pages of mathematical and graphical treatment—all theoretical, almost nothing about instruments. It is supplemented by Appendix A consisting of twelve tables of properties which take up 66 pages, of four large folded Mollier charts and of two Ellenwood charts—a grand total of 143 pages and four folded charts, which in itself constitutes a splendid reference treatise—but a reference treatise for the student rather than for the engineer; and a reference work that cannot by any stretch of imagination come under the heading of "Engineering Instruments."

On the other hand, one is astonished at the omission of presumably essential theoretical discussions. Example, at the start of the chapter on "Measurement of Temperature" (64 pages) the authors state that "The establishment of the absolute thermodynamic scale of temperature and of the centigrade thermodynamic scale is a rather complex matter, a discussion of which is here unnecessary." In the first place such an omission appears to be inconsistent with the primarily reference character of the book and with the profusion of purely theoretical dissertation which properly make up most of the volume. In the second place this book, filled as it is with mathematical treatments and "intended both for the student in engineering schools and for the practicing engineer" (preface) is obviously intended for the *graduate* practicing engineer who can understand it. The reviewers, who speak from years of practical experience in heat technology, hold firmly to the conviction that such an engineer needs to have in mind a clear understanding of The Scale of Temperature. The distinction between an engineer and a mechanic resembles in this aspect the distinction between a composer of real music and a Tin Pan Alley plugger: In both instances the former understands scales while the latter merely works with them.

Perhaps the reviewers have no right to raise the question of "inconsistency," for after all the authors are in much better position to evaluate the relative importance of the various subjects assigned to engineering students. Our concern, we hasten to explain, is not so much for the students who may be required to consult the book, as for the practicing engineer who may require himself to refer to it in connection with his bread-and-butter work. There's a difference!

But if one notices such flaws at all, it is for exactly the reason that flaws stand out "in gems of purest ray serene" which would pass unnoticed in semi-precious stones. This work is of such value that one cannot help wishing that it were altogether perfect. The plain fact is that with twice as many omissions it would still tower as a glorious accession to scientific (and industrial?) literature; it would still shine as a triumph of American scholarship.—M. F. Behar & Richard Rimbach.

The Handbook of Industrial Instruments

M. F. Béhar*

CHAPTER IX†

Industrial Humidity Instruments

Section 1. General data and summarized laws‡
Section 2. Importance with regard to materials‡
Section 3. Importance with regard to comfort and health‡
Section 4. The measurement of humidity
Section 5. Indicating Instruments
Section 6. Recording Instruments
Section 7. Automatic Control

1. General Data and Summarized Laws

Humidity is simply the invisible water vapor in the air. The word humidity, so loosely applied in every-day speech that it has lost any definite meaning, can seldom be used by itself in technical discussions. The expression *absolute humidity* specifically denotes the quantity of water vapor per unit *volume* of air, which in the United States is generally expressed (1) in grains per cubic foot when speaking of air conditioning and more correctly, (2) in terms of vapor pressure.

Throughout this Handbook, the word humidity, however qualified, refers to water vapor in the atmosphere—in rooms or in enclosed processing equipment; while the expression *moisture content*, although applicable to air, is generally reserved for substances other than air. Moisture content is closely related to atmospheric relative humidity, but its measurement cannot at all (and its control cannot at length) be discussed in this chapter—they are dealt with in later chapters on Properties of Matter, on Proportioning and on specific industrial processes.

Atmospheric humidity measurement and control are of importance in industry on account of the effects of air on all workers and on all substances. Air conditioning, involving as it does equipment as well as instruments, is not itself the subject of this chapter, but before coming to industrial humidity instruments it is necessary (as it was with temperature instruments) to discuss briefly the subject of atmospheric humidity, and incidentally of other air conditions.

Facts About Air

Air is a physical mixture of gases and vapors comprising three groups. Gases of the first group are present in the air in almost constant proportions which for *dry* air are approximately as follows:

	By weight	*By volume*
Nitrogen	75.5%	78.1%
Oxygen	23.1	21.0
Argon, etc.	1.4	.9
	100.0	100.0

*Engineering Editor.

†Owing to the length of Chapter II (Temperature) which constituted seven instalments of this Handbook, from February to August, inclusive—161 pages—it has been decided to divide it into seven chapters (II to VIII) for the bound edition of the Handbook. This chapter, which immediately follows, is therefore the ninth.

‡Grateful acknowledgment for assistance in the preparation of the introductory sections of this chapter is made to the American Society of Heating & Ventilating Engineers, to the Carrier Engineering Corporation and to the Parks-Cramer Company.

The second group includes such accidental gases as ozone, ammonia, sulphur dioxide, etc., seldom present except in very small proportions.

The third group comprises:

Water vapor
CO_2 and
Dust

These are present in the air in widely varying proportions. It is this group which is of importance in connection with the subject of air conditioning.

The gases of the first group have fairly constant effects, to which living organisms have become accustomed. When dangerous gases of the second group such as ammonia and sulphur dioxide are generated under special conditions, it is necessary to take special means to combat them. Constituents of the third group are always present to some extent, and their effects have an important bearing on health, on the economics of manufacturing and commerce. Especially is this true of water vapor.

The physical properties of the air most pertinent to our subject are as follows:

Property	*Customary Unit of Measure*
Density or weight	Pounds per cubic foot
Pressure	Pounds per square inch or inches of mercury
Temperature	Degrees Fahrenheit
Heat Content	B. t. u. per pound or B. t. u. per cubic foot
Humidity	Grains of water per cubic foot ("absolute") or per cent of saturation ("relative")
Velocity	Feet per second (circulation) or miles per hour (wind)

Air has appreciable density and constantly exerts a pressure, called barometric pressure, on all sides of a body exposed to it, equal per square inch to the weight of a column of air one square inch in section extending up through the whole layer. This is the same as the pressure of a column of water approximately 34 feet high. It is equal to about 14.7 pounds at sea level under normal conditions of weather. "Standard barometric pressure" at sea level is 29.92 inches of mercury (roughly, 30 inches), which corresponds to 14.7 pounds per square inch. Local barometric pressure is affected by the altitude above the sea level, temperature, humidity and wind conditions.

Dry air at sea level and at a temperature of 70°F weighs approximately 0.075 pounds per cubic foot. As air expands or contracts with changes in the temperature or pressure its density varies nearly in accordance with the fundamental gas laws:

(1) At a constant temperature the volume varies inversely as the absolute pressure (Boyle's or Marriotte's Law.)

(2) At a constant pressure the volume varies directly as the absolute temperature (Charles' Law.)

(3) At a constant volume the pressure varies directly as the absolute temperature (Charles' Law.)

(4) Combining the above laws there is the general relationship $PV = KT$, where P = absolute pressure, V = volume, K = a constant depending upon the kind and quantity of the gas and units of measurement, and T = absolute temperature. In the case of air, if P is the pressure in pounds per square inch, V the number of cubic feet per pound, and T the absolute temperature in degrees Fahrenheit, then $K = 0.370$.

Water and Water Vapor

The relative amount of space occupied by a given weight of water in its different states may be seen from the following table:

State	Weight of one Cu. Ft. Pounds	Relative Volume Occupied by One Pound
Water at 70°F	62.3	1.00
Ice at 32°	57.5	1.08
Steam at 212° and atmospheric pressure	0.037	1700.
Atmospheric water vapor at 70° temperature and 65% relative humidity	0.00075	83000.

With each change in the state of a quantity of water its heat content or internal energy is greatly changed. The standard unit of heat used in engineering—the B. t. u.—is the average quantity of heat required to raise the temperature of one pound of pure *water* 1°F.

The mean specific heat of water is unity and is taken as the standard. Few substances have a higher specific heat than pure water. The specific heat of dry air at constant pressure and ordinary temperatures is 0.2417.

The amount of heat needed to bring the temperature of water from 32° to any given temperature (heat of the liquid) is equal to the specific heat times the degreees rise from 32. The heat of the liquid of one pound of water at 212° is 180 B. t. u. At 212° (and std. bar. pr.) further addition of heat will cause boiling, the temperature remaining constant until all the water is evaporated. 970 B. t. u. will be required to vaporize completely the pound of water. This is called the latent heat of vaporization. It varies with the temperature during vaporization. The lower the temperature, the higher the latent heat of vaporization.

The total heat of steam is the amount necessary to convert one pound of water at 32° to one pound of steam at any given temperature and pressure. Thus the total heat of dry saturated steam at 212° is 180 + 970 = 1150 B. t. u. per pound.

The evaporation of one pound of water from a humidifier at room temperature (70°F) requires a large amount of heat, namely, 1052 B. t. u. Its mechanical equivalent is equal to the energy required to lift a man weighing 155 pounds from sea-level to the top of a mountain over a mile high. In terms of power, the heat equivalent of one horse-power will evaporate less than five-eights of an ounce of water per minute.

Evaporation may be rapid and intense, pervading the mass of liquid, as in boiling, or slow as in the case of natural evaporation. Slow evaporation takes place at ordinary temperatures from all surfaces of water exposed to unsaturated air (see below) and even from the surface of ice.

Heat must be supplied from some source *whenever evaporation takes place*, and if there is no other source the *air*, water, or surrounding objects must furnish it and be correspondingly cooled. This explains the lowering of the temperature in a room when humidifiers are in operation, which on a warm day often amounts to 10°F. It also explains how air can be cooled without the use of cold water or refrigeration, by the process of "evaporative cooling" which consists of passing the hot outdoor air through humidifiers where it cools itself considerably by evaporating water (and incidentally saturating itself—after which it is *heated* until its *relative* humidity is as required.)

In steam generation it usually happens that tiny particles of free moisture are carried into space with the vapor. When the space contains all the

vapor it can hold it is said to be saturated. If free moisture is also present the steam is called *wet saturated;* if vapor alone is present it is called *dry saturated.* Suppose the steam already produced be still further heated after all the water is completely evaporated. Its temperature will rise and it will become *superheated steam.* Water vapor in unsaturated air is virtually superheated steam.

"*Saturated Air*"—Water vapor differs from other constituents of the atmosphere in one very important respect. In a given volume of space there can exist no more than a certain definite quantity of water vapor (usually expressed in grains per cubic foot) at any given temperature. When the atmosphere contains this limiting maximum of water vapor we have what is called "saturated air"—air which is saturated with moisture. The only factor which can affect this maximum is temperature. As temperature rises there is a corresponding increase in the amount of vapor each cubic foot of space can hold. It is important to note that the presence of the air in space has no effect on the maximum amount of water vapor which may be present (except that air retards the diffusion of the vapor particles). Thus the weight of water vapor in saturated air at a given temperature is exactly the same as that of "saturated aqueous vapor" or dry saturated steam at the same temperature when no air is present. Therefore, air is said to be saturated with water vapor when the proportion present, at any given temperature, is such as to exert a partial pressure equal to the pressure of saturation corresponding to the given temperature. Vapor pressure is independent of atmospheric pressure since the vapor and the dry air coexist side by side. It is now apparent that barometric pressure is the sum of the weights of a column of dry air and a column of vapor, the latter occupying the same space as does the lower portion of the former—up to about 50,000 feet.

Another way of putting it is as follows: Air is said to be saturated with moisture when the space occupied jointly by air and water vapor contains the maximum amount of water vapor possible to remain in the gaseous state at the existing temperature.

It is not amiss to have in mind the clearest possible concept of saturated air, because the aspects of humidity in which the engineer is interested—evaporative or moistening power, working conditions, etc.—are measured in terms of percentage of saturation.

"*Dew Point*"—Fog is a universally known indication that the atmosphere contains *more* water per cubic foot than it can hold as invisible vapor at the temperature of itself and of the water vapor. The excess H_2O can no longer exist in the gaseous state and therefore passes into the liquid state. Condensation is the reverse of evaporation. Mention was made above of the large amount of heat required for evaporation. Conversely, for every pound of water vapor which condenses into water, there is an evolution of heat. Reversing the above statement on evaporating one pound of water, we can say that the condensation of one pound of water vapor in air at 70° to water at 70°F evolves 1052 B. t. u.

Water vapor and air occupying the same space have the same temperature. When air is saturated, the water vapor is saturated steam; when air is below saturation point the vapor is superheated steam; when air is foggy it almost always contains wet saturated steam.

The mere presence of fog in air does not make the air supersaturated and we purposely use the expression foggy and not "supersaturated air" because the latter expression refers to a condition of relative humidity higher than 100%. This condition seldom, if ever, occurs in practice. It could happen only in special instances when air which is quite free from dust or other impurities in cooled below the dew point. On the other hand saturated air containing free moisture in suspension is common. To be supersaturated the air must be 100% saturated with vapor in addition to having free moisture in suspension.

These technical points having been mentioned for the sake of accuracy, we may now forget them in order to simplify the discussion, and consider that fog or mist—in a workroom or in a kiln or other enclosed equipment—denoted supersaturated air.

There are two well-known ways of saturating or supersaturating air: by cooling it, or by humidifying it. The cooling method need not involve known volumes of air: a cold surface, of known temperature, may be used: If we expose to the air a polished vessel such as a silver pitcher filled with water, and gradually cool the water by slowly adding ice, its temperature will eventually fall to a point where a film of condensed moisture appears upon the polished surface. The adjacent air, together with its humidity, has been cooled to the degree corresponding to saturation for the weight of water vapor it contains per unit volume. This degree of temperature is known as the dew point. For any given temperature of the air, the dew point depends entirely upon the quantity of water vapor per cubic foot, that is to say its absolute humidity. The dew point temperature is the saturation temperature. This permits the exact determination of atmospheric humidity by means of the dew point apparatus, as will be set forth below under Measurement.

Relative Humidity

The higher the temperature, the greater the quantity of water vapor which a given volume of air (strictly speaking, of space) can hold. On a cold day (32°F) two grains of humidity saturates a cubic foot of air; on a hot day (100°F) twenty grains—the barometer reading 30 inches on both days. If saturated atmosphere is drawn from outdoors on a freezing day, and heated to 100°F, its humidity (absolute) will remain the same, but it will hold one-tenth of the humidity required for saturation at the higher temperature. It will "feel dry" because its *relative* humidity will be low. It will have a relative humidity of ten percent.

Evaporative and Moistening Power—It therefore is not the mere humidity of the air (quantity of water vapor in each cubic foot) which is of importance in connection with bodily comfort and with hygroscopic substances, but its relative humidity—the ratio of the quantity of vapor actually present in a given volume at a given temperature, to the quantity of vapor which would saturate the same volume at the same temperature. This difference, or "deficiency" as it is sometimes called, is the true measure of evaporative power. In engineering practice, as well as in the scientific laboratory, relative humidity is expressed as a percentage, 100% being the saturation point. Deficiency is the basis of some calculations involving *rate* of evaporation. For most hygroscopic substances the evaporative power of a stream of air of 60% relative humidity at a dry-bulb temperature of 90°F approximately equals that of a stream of air at 40°F whose relative humidity is also 60%, regardless of the fact that each cubic foot of the first stream carries about five times the quantity of water carried by an equal volume of the second stream (circulation and pressure being equal). The same applies

to the moistening effect or moistening power of air, which is so important in textile and other industries. For example, the moisture-carrying capacity of air at 70°F is 8 grains per cubic foot. If the air contains but 4 grains per cubic foot its relative humidity is 50%. If this same air is heated to 83°F its capacity to hold water vapor is thereby increased to 12 grains per cubic foot. Since it will contain but the original 4 grains of vapor per cubic foot its relative humidity will drop to 4/12 or 33-1/3%. The 70° air, whose relative humidity is 50%, will exert a greater moistening effect than the 83° air, whose relative humidity is 33-1/3%, although the actual quantity of moisture is the same in both cases.

Vapor Pressure and Behavior of Vapor in Air—Water vapor is a gas. Its expansive force imposes upon all surrounding surfaces a pressure which varies with the density of the vapor. At any given temperature the vapor pressure may reach but cannot exceed a certain maximum which exists when the vapor is saturated. In dealing with atmospheric conditions, the expression vapor pressure refers only to that component of the existing atmospheric pressure which is due to the amount of water vapor present. If, in a vacuous container with a content of one cubic foot, we allow water to evaporate, maintaining meanwhile a constant temperature of 70° both in the liquid and the vapor, the space will become filled and the vapor saturated when 8.1 grains of water have been converted into vapor. The vapor pressure will then be 0.36 pounds per square inch absolute, and no more vapor can be introduced by evaporation unless accompanied by a rise in temperature and pressure.

Should we now fill a second and like container with one cubic foot of dry air at the same temperature of 70° and at normal atmospheric pressure of 14.70 pounds per square inch, the contained air would weigh 524.6 grains—65 times as much as the equal volume of water vapor at the same temperature.

If we now admit dry air at the same temperature to the first container, allowing it to mingle with the vapor, we shall find that 511.7 grains of air will suffice to raise the pressure to that of the atmosphere. We now have:

	Weight Grains	*Pressure Pounds*	*Temp. F.*
In the First Container			
Saturated Water Vapor	8.1.	0.36	70°
Air	511.7	14.34	70°
Saturated Air	519.8	14.70	70°
In the Second Container			
Dry Air	524.6	14.70	70°

The pressure resulting from the mingling of the air and vapor in the first container is explained by Dalton's Law: in a given volume the total pressure of a mixture of several gases is equal to the sum of the pressures which the gases would respectively exert if separately existing in the same volume and at the same temperature. This explains why dry air, being heavier than water vapor, is also heavier than humid air at the same temperature and pressure

An important distinction between saturated and non-saturated (superheated) vapor should be noted. Non-saturated vapor is a gas. It contracts and expands approximately according to the gas laws. On the other hand, saturated vapor in contact with its liquid and at a given temperature can neither be compressed nor expanded. Either by condensation of some of the vapor, or by further evaporation of the liquid, the vapor pressure and the weight of moisture per cubic foot will remain absolutely constant as long as the vapor is saturated.

Barometric pressure has no effect upon the maximum possible weight of vapor per cubic foot or the vapor pressure at saturation. It does, however, affect the *rate* at which evaporation of water takes place. In a perfect vacuum, water would instantly "flash" into vapor and be diffused.

As non-saturated air approaches saturation with water vapor, the vapor pressure increases until equilibrium between the vapor pressure and the evaporative tendency of the liquid is finally established at the point of saturation. Water exposed to air not saturated with water vapor will evaporate continually until saturation occurs. Complete saturation will not be possible in the open, because as the degree of saturation increases immediately above the surface of the water, rapid diffusion of the vapor into the less humid space around it will occur.

The *rate* of evaporation of water will be increased by any of the following factors:

(1) Reduction of the amount of vapor in the contiguous air, or increase in the "deficiency."
(2) Rise in temperature.
(3) Lowering of atmospheric pressure.
(4) More rapid air circulation over the surface of the water.
(5) Increase in the surface area of the water being evaporated.

Vapor Pressure and Humidity—Since Boyle's Law applies to non-saturated vapors as well as to gases, the volume of one pound of water vapor at a constant temperature varies inversely with the vapor pressure. At a given temperature, therefore, the vapor pressure is always directly proportional to the weight of water vapor per cubic foot, that is to say, to the absolute humidity. By reason of this it is possible to define relative humidity in terms of vapor pressure rather than in terms of the weight of vapor actually present and the weight at saturation. Thus the relative humidity is the ratio of the actual vapor pressure to the maximum vapor pressure at the same temperature. (The actual vapor pressure is the same as the pressure of saturated vapor at the dew point temperature. The maximum vapor pressure is the same as the pressure of saturated vapor at the existing dry-bulb temperature of the air.)

Example—Saturated air at 70° has a vapor pressure of 0.740 inches of mercury, and a moisture content of 8.07 grains per cubic foot. If the vapor pressure of the air in a room is only 0.540 when the temperature is 70°, its relative humidity is 0.540 divided by 0.740, or 73%. The corresponding moisture content is then 73% of 8.07, or 5.89 grains. If we gradually cool this air, its relative humidity rises until saturation is reached at 61.0°. Owing to the slight contraction caused by cooling, the absolute humidity meanwhile increases to 6.00 grains, but the vapor pressure remains constant at 0.540. If cooling is continued below 61.0°, moisture will condense and appear as fog, dew, or rain. This critical temperature is the dew point. It was mentioned above that dew point depends on *quantity* of vapor. Equally, for any given value of vapor *pressure*, there is a corresponding and fixed dew point or saturation temperature.

Wet-bulb Temperature

A moistened finger feels cold. It feels colder when exposed to rapid circulation. We have seen the reasons: first, evaporation requires heat; second, temperature varies with degree of saturation; third, circulation removes saturated air in contact with water on finger and increases rate of evaporation and hence rate of heat demand on skin.

In saturated air the moistened finger will not feel cold. The drier the air the colder the finger feels because the faster the water evaporates. This

familiar phenomenon is utilized in the principal class of industrial instruments for measuring atmospheric humidity. These instruments consist of two thermometers whose bulbs are placed side by side. One bulb is dry, the other is generally enclosed in a wet wick (see Section 5 for various wet-bulb methods). The latter naturally reads lower in unsaturated air.

The wet-bulb temperature, in unsaturated air, is *not* the dew-point: it always lies above the dew-point and below the dry-bulb temperature. The question is sometimes asked why this is so—why the wet-bulb temperature is not the same as the dew-point.

It is difficult to explain why without dragging in formulas, and as a matter of fact while wet-bulb temperature calculations are to be found in some chemistry books, in technical papers presented by Willis Carrier and others, and notably in the only textbook on humidity: Bongards' *Feuchtigkeits-Messung*, the question has never been answered, to our knowledge, for the benefit of the average industrial engineer. The following may perhaps shed some light on the subject:

First of all, let us all agree just what a "wet bulb" is. The bulb part of it is the temperature measuring device. Therefore let us exclude it. Let us also exclude the wick, porous sleeve or other mechanical means. What remains? Simply a film of water with a very large surface compared to its mass.

The idea is, of course, that the initial temperature of the water which is supplied from the inverted flask or other source must not affect the wet-bulb temperature. If the supply of water is too cold, the indicated temperature would be too low, if the water is too hot, the wet-bulb thermometer will read too high. The smaller the volume of water the smaller the error. But if the water is supplied at the wet-bulb temperature, its volume as compared to its surface will not matter.

Next let us reason as did Stuart W. Cramer when he did away entirely with the wick. The sole function of the wick, he said, was to obtain water whose surface is large compared to its volume, and the same effect can be obtained by *finely atomizing the water*.

It is obvious that the only difference between a wick and a spray is one of *form*. The effect is the same. The result should be the same, that is to say, the temperature of the mist (humidified saturated air) issuing from an atomizer or humidifier should be the same as that indicated by a wet-bulb thermometer.

As a matter of fact it is—provided only that the water supply, as mentioned above, be of approximately the wet-bulb temperature.

Having thus got rid of the complication of the wick, we can now proceed to discover why the wet-bulb temperature is somewhere between the dew-point and the dry-bulb temperature. We can now deal with air, water and water vapor, and apply the laws discussed in the last few pages.

Assume a dry-bulb temperature of 92°F and a relative humidity of 30%—typical summer air. The absolute humidity of 4.8 grains. At 92°, a cubic foot of air of 100% relative humidity will hold 15.9 grains. If instead of saturating it by adding the required 11.1 grains of vapor, we saturate it by cooling it to the dew-point, we find that this dew-point is 56°.

Saturating this cubic foot of air by mixing it with atomized water—initially *liquid* water—is a totally different procedure. The water evaporates, therefore it cools the air. But the evaporation of the water results in *vapor* which simultaneously increases the relative humidity until it is 100%. The final temperature must be lower than 92° because we have cooled the air; it must be higher than 56° (the dew-point of our original

room air) because we have increased the absolute humidity. Therefore the final temperature must be somewhere between the dry-bulb temperature and the dew-point.

Experiments would show that in the process of spraying we have added 3.0 grains of moisture, the final absolute humidity being 4.8 + 3.0 = 7.8 grains. The saturation temperature for 7.8 grains per cubic foot is 69°. We would find that the final temperature of our mixture is exactly 69°.

Comparing now a wet-bulb thermometer (properly fanned, of course) in air that has a dry-bulb temperature of 92° and a relative humidity of 30%, we find that it reads exactly 69°.

Conditions in and about an ordinary wick or porous-sleeve wet-bulb are essentially the same as in the above example: The air in contact with the wet-bulb is cooled by the evaporation and at the same time it is humidified so that its dew-point is raised. Equilibrium depends on the specific heats of air and water and on the heat of evaporation of water. The laws apply equally and the final result is always the same except when the temperature of the water supply differs too much or—and this important—when lack of adequate circulation allows the surrounding saturated air and the wet-bulb itself to be heated by radiation from objects in the room and by the room air, to a point *between* the true wet-bulb temperature and the dry-bulb temperature. More about this under psychrometers in Section 5.

(The fact that saturated air, plus spray, discharged by a humidifier, is delivered very close to the wet-bulb temperature of the room air which enters it, is utilized in some humidity instruments, notably the Parks-Cramer regulator. See Section 7.)

2. Importance with Regard to MATERIALS

Very likely, most readers of this chapter are already personally interested in humidity measurements and control by reason of being concerned with processes involving hygroscopic materials or otherwise calling for air conditioning either in rooms or in enclosed equipment. Almost all materials are hygroscopic—even some metals and alloys. And most materials which are very slightly hygroscopic, such as metals, are often affected on the surface, at least, by atmospheric humidity. Disregarding these latter effects, disregarding effects on bodily health which are dealt with in the next section, and considering only the relation between atmospheric humidity and the moisture content of materials, one finds that almost every industry is affected. Humidity, as one of the ten working or processing conditions listed in Chapter I, is second only to Temperature. In some industries or processes it is desired to avoid the costly effects of dry air; in others it is desired to dry materials efficiently and economically—which requires control of temperature, humidity and circulation and in many cases (e. g. hardening finishes) removal of dust from the air before it is used. In some industries the air must be humidified to a definite percent of relative humidity, which varies with the departments; in others it must be de-humidified. In winter, air must generally be considerably humidified as well as heated; in summer it must sometimes be cooled and either humidified or de-humidified. It is obvious that humidity control involves temperature control. Some humidity measuring instruments, as will be seen, are primarily thermometric instruments, and some humidity controllers are fundamentally temperature controllers.

Such is the relation between hygroscopic materials and atmospheric relative humidity that the *conditioning of materials* involves in many cases nothing more than controlling the relative humidity of the air, provided the temperature does not fluctuate too much. For every given percentage of relative humidity of the air in which most materials are placed, there is a corresponding percentage of moisture content. (The effect of temperature variation with constant relative humidity, is slight.) Equilibrium is attained very quickly in the case of fibres (a matter of seconds or minutes); somewhat more slowly in the case of dough, paste goods, etc.; even more slowly in the case of clay products; while lumber takes days in kilns, or weeks or months in drying lofts, before attaining equilibrium. The relation of exposed surface to mass if of course the prime determining factor, but both temperature and humidity affect the *rate* considerably. Thus certain dimensions of hardwood which formerly required months or years of seasoning in lofts now require less than two weeks of controlled kiln drying, from green lumber to marketable furniture stock.

Of all industries, the textile industry is most vitally concerned with humidity control, in humidification of rooms and in control of atmosphere in drying apparatus. This follows from the extremely hygroscopic nature of all textile fibres, which vary in strength, in spinning and weaving properties and in economic value in accordance with the relative humidity of the air. So delicately sensitive are textile fibres to atmospheric moisture that mill engineers often speak of *atmospheric* conditions in terms of fibre "regain." This is natural, because regain or moisture content (the terms are not interchangeable; see below) do not always correspond exactly to relative humidity in the case of some fibres. The "standard atmosphere" in the case of cotton regain calculations, for example, is 70°F and 65% relative humidity, but if the temperature is 60° the R. H. must be 64%; at 80° 66%, and at 90°, 67%.

Engineers in other industries where hygroscopic materials are processed will find it interesting to study the results of textile specialists' research along this line, which has been carried on for many years, until a number of laws have been formulated and a number of charts and tables published. Long books are devoted to studies of the relations between atmospheric conditions and various fibrous materials. A brief summary of general interest is not amiss here:

Regain is the percentage of hygroscopic moisture present in a mass of material based upon the dry weight of fibre present. Thus, if a mass of wool which initially weighs 120 ounces, be dried out and then found to weigh only 100 ounces, it must have contained 20 parts of moisture against 100 parts of dry fibre weight, representing an initial regain of 20%. Moisture content or "percent of moisture" refers to the weight of moisture compared with the combined weight as a basis of a percentage. In the case just cited the "percent of moisture" is that corresponding to 20 parts in 120, or 16 2/3%.

Regain is the accepted index of *hygroscopic* moisture content. It is more convenient for computation and general use than "percent of moisture." The latter term is convenient for dealing with the condition of materials containing *free* as well as hygroscopic moisture. *The use of the term regain implies that hygroscopic moisture only is present.* In materials other than textiles, free moisture is a factor of importance. In lumber, for instance, water exists in four distinct forms. The same holds true for meat, fish, etc., and is of importance in refrigeration engineering.

Raw wool raised in the dry climate of our southwest states gains considerably in weight by absorption of hygroscopic moisture during transportation to the eastern market. Since wool is sold by the pound this gain in weight increases its marketable value.

Of good raw cotton taken from the bale and fed to the pickers, from 85% to 90% by weight will appear in the finished yarn. The loss represents leaf, seeds, dirt, imperfect fibre and usually some hygroscopic moisture. The regain of cotton in the bale often equals and sometimes exceeds 10%—a condition seldom realized in finished cotton products: The loss of hygroscopic moisture therefore is obviously a factor in the total loss.

Regain becomes a very important consideration when impurities have been eliminated and the cost of manufacture has increased values. The basis of regain arose first in the raw silk trade, because of exceptionally high values involved. Silk is purchased in a partially finished state, practically free from such impurities as are present in raw wool and cotton. The practice resulted in the adoption of a standard of 11% regain.

The constant automatic control of temperature and humidity in the textile mill—

(1) Regulates the pliability or workability of the fibres in each process of manufacture and thereby insures maximum production, minimum loss, highest quality of product and least manufacturing cost.

(2) Minimizes the production of "fly."

(3) Reduces the number of broken ends by insuring a yarn of great strength and uniformity.

(4) Insures a yarn of definite, uniform weight. Control of weight of finished yarn often results in a saving of thousands of dollars per year.

(5) Guarantees maximum strength and uniformity of finished yarn.

(6) Increases the mechanical efficiency of the mill because the uniform yarn makes possible a finer adjustment of spinning frames or looms and these will remain in adjustment without frequent attention.

(7) Eliminates generation of static electricity.

(8) Guarantees uniform width of woven fabrics and freedom from defects.

The general laws relating to regain in textiles as deduced from the research of Hartshorne and his predecessors are now generally accepted as demonstrated fact and may be broadly summarized as follows:

(1) *In a given mass* of textile material *in hygroscopic equilibrium* with the atmosphere to which it is exposed, the regain depends upon the humidity and the temperature.

(2) The regain acquired at equilibrium *under a specified condition of temperature and humidity* depends chiefly upon the material—that is, whether it is cotton, wool, silk, etc. Different materials and in some cases, though to a less extent, different grades of the same material, have marked differences in hygroscopic property. The manner in which the material is exposed to the atmosphere, such as in the loose skein or tightly wound on the bobbin, is also a factor, although the relative extent to which the ultimate regain and the time necessary for reaching equilibrium are affected, is a problem for further experimentation.

(3) The hygroscopic properties of a given material are subject to temporary or permanent alteration by virtue of high temperature, chemical decomposition, excessive presence of dust, dirt, or foreign matter, etc., but in general clean specimens of the same material similarly exposed will repeatedly absorb the same amounts of moisture under corresponding conditions of humidity and temperature if given sufficient time to reach an actual equilibrium.

(4) *The rate* at which any textile material undergoes a change in moisture content in response to changes in humidity and temperature is dependent upon such variable factors as previous moisture condition of the material; rate and magnitude of change in atmospheric conditions; size, shape, density and exposed area of the material mass, and rate or intensity of air circulation. The time varies according to circumstances but even under ordinary conditions the lapse of hours, days or even weeks may be required for the attainment of *complete* hygroscopic equilibrium.

(5) At a given relative humidity, regain is less at high temperatures than at low. (According to Hartsthorne the regain for cotton at constant relative humidity varies inversely as the absolute temperature, and for wool it varies inversely as the three-halves power of the absolute temperature.)

(6) To maintain a constant condition of regain it is necessary as the temperature rises to increase the relative humidity and, conversely, as the temperature falls to decrease the relative humidity.

(7) Within the ranges of temperature and humidity which prevail in the textile mill, the rate at which humidity should increase as temperature rises in order to maintain a constant regain condition is practically constant.

3. Importance with Regard to Health and Comfort

This section, too, need only be a brief summary, for the reader of this chapter has no doubt studied the subject. Indeed, engineers appear to be more progressive than physicians when it comes to conditioning air for the sake of human comfort—as witness the fact that the proportion of air-conditioned large industrial plants is enormously greater than the proportion of air-conditioned large hospitals. Perhaps the credit belongs not only to the engineers but to the management which *invests* in good working conditions and correctly expects a good return in increased production, lower labor turnover, minimized plant hospital budget, etc. As a matter of fact the class of buildings which shows the greatest proportion of air-conditioning installations is the modern "movie palace" class.

At the outset it is necessary to point out that while a great deal of research has been done on *comfort*, little has been done on *health*. "Since the prolonged effects of temperature, humidity and air movement on health are not so well known as their effects on comfort, the optimum conditions for comfort cannot be regarded as necessarily identical with those for health."

Valuable data have been obtained on physiological reactions to air conditions and on "Effective Temperatures" (the air conditions at which average persons are comfortable). The work was carried out in the Research Laboratory of the Am. Soc. Heat.-Vent. Engrs. associated with the U. S. Bureau of Mines Experimental Station at Pittsburgh. Many medical scientists collaborated in the work on physiological reactions. These records stand today as the only scientific and authoritative body of data available. Though most of this work was directed toward determination of comfort effects, some of it was devoted to the development of physiological data.

The following summary of results in quoted verbatim:*

(1) There is an inability of the body at rest and in still air to compensate for saturated atmospheric conditions exceeding 90° F.

(2) The physiological effects resulting from exposure to high temperature and humidities depend upon both wet- and dry-bulb temperature readings.

(3) The exhaustion and weakness following subjection of human beings to a very high temperature and humidity for a short period is not so severe as subjection to a moderately high temperature and humidity, but for a longer period.

(4) The highest dry- and wet-bulb temperatures attained and length of time endured in the experiments are as follows:

Dry-bulb	Wet-bulb	Relative Humidity	Time Minutes
112.5	112.5	100	35
120.2	104.02	60	40
147	108.4	30	45
157	100.43	15	45

(5) The pulse-rate, rather than the rise in body temperature, apparently determines the extent of the discomfort experienced by the subject. Subjects became very uncomfortable after the pulse-rate exceeded 135 pulsations per min., and complained of unbearable and distressing symptons when the pulse exceeded 160 per min. The highest pulse-rate recorded was 184 per min.

(6) The systolic and diastolic blood pressure fell with moderate increase in temperature and humidity, and the systolic rose and the diastolic fell, thus increasing the pulse pressure, in high temperatures and humidities.

*W. J. McConnell and F. C. Houghten, *Body Temperatures and their Measurement*, Trans., Am. Soc. Heat.-Vent. Engrs., Vol. 28.

(7) The curve of rectal temperature shows a close parallelism with the curve of the temperature of the test chamber at any constant humidity.

(8) Subjection to high temperatures and humidities produced no marked change in the respiratory rate.

(9) Loss of weight varies with the individual, the loss increasing with the length of exposure to high temperatures and with the severity of the test.

(10) The haemoglobin content of the blood increases proportionately to the loss in weight.

(11) An estimation of the changes in the sugar content of the blood proved negligible.

(12) A relative increase in the blood count was found, but not an absolute one.

(13) The rate of sweating varies with the atmospheric conditions. The loss of substances from the body through the sweat do not change in their proportions to one another.

(14) Examination of the urine was negative for albumen and sugar, and specific gravity increased.

(15) The sweat is the chief factor in producing the irritation and inflammation of the eyes.

(16) Ice water, even when large quantities were swallowed, did not cause cramps under the conditions of the experiments.

Early in 1923, these same investigators, McConnell and Houghten, together with F. M. Phillips, of the United States Public Health Service, presented another paper, *Further Study of Physiological Reactions*,* which is a valuable elaboration of their prior work, including further detailed observations, and which establishes definitely the all-important fact, that the dry-bulb temperature is an exceedingly poor index of human physiological reactions or of human comfort. This research demonstrates, further, that the wet-bulb temperature, though, with the dry-bulb, the indicator of the air's humidity, is, taken alone, also an inadequate index as to reaction and comfort, and in this paper the authors introduced the term "*Effective Temperature*,"—meaning a *condition* of the atmosphere to which human beings react with a certain determined (averaged) sensation of comfort.

A given Effective Temperature, say 65°, in air of 100 ft. per min. velocity, may mean a dry-bulb of 67°, with a relative humidity of 100 per cent, or a dry-bulb of 74.5° with a relative humidity of 10 per cent. The "Effective Temperature" line marks a series of dry-bulb, wet-bulb and relative humidity relationships between such limits, any one of which appears to be as "comfortable" as any other. Note that the "Effective Temperature" pertains only to comfort, the physiological relationship being open to much further investigation.

The term Effective Temperature is unfortunate since it expresses the *condition* of the air as to dry-bulb temperature, wet-bulb temperature, and, hence, relative humidity. This unfortunate nomenclature has led, also, to certain faulty methods of presenting the graphed data, the charts showing Effective Temperatures that correspond to extreme dry-bulb temperatures and percentages of relative humidity which are not actually comfortable, and are strongly suspicious as to healthfulness, under normal conditions. This fault can be corrected, and the charts made much more useful if it is borne in mind that the great majority of people, normally clothed and normally active, should not, at any dry-bulb temperature (unless there is some ruling industrial or process condition), be subjected to percentages of relative humidity less than 30 nor more than 60.†

The Comfort Zone shown on the charts should, then, for strictly personal (i.e. not industrial) purposes be reduced to include only that portion of the shaded area between the 30 per cent and 60 per cent relative humidity lines. An inspection of the chart, Fig. 156 for still air, shows that this limits dry-bulb temperatures between 64.5° and 77°, at 60 per cent and 30 per cent relative humidity, respectively. As a matter of fact observations of air conditioning engineers indicate that the most comfortable and, presumably, healthy percentage of relative humidity, for normal slight activity, is between 40 and 50%, and this degree of saturation is, also, about the highest permissible in average buildings (those not specifically constructed to permit high humidities for process rather than personal reasons) without undue condensation upon windows and other cold surfaces.

In January 1924, another paper‡ was presented to the Society, in which were developed the following conclusions:

(1) Air motion exerts a cooling effect on the human body in atmospheres where the temperature is less than that of the body; in temperatures above that of the body air motion in-

*Trans. Am. Soc. Heat.-Vent. Engrs., Vol. 29.

†The Am Soc. Heat-Vent Engrs. Guide, 1929, Pg. 378.

‡*Air Motion—High Temperatures and various Humidities—Reaction on Human Beings*, W. J. McConnell, F. C. Houghten and C. P. Yaglou, Trans. Am. Soc. Heat.-Vent. Engrs., Vol. 30, 1924.

creases the discomfort, but the rate of change in reactions cannot be doubled by doubling the velocity of the air.

(2) Within the range of the experiments no appreciable change in the period of endurance resulted from air motion as indicated by the series of tests in still and in moving air.

(3) The pulse-rate appears to be the best index to the severity of the discomfort.

(4) The correlation between the pulse frequency and body temperature is not constant.

(5) The systolic blood pressure increases on exposure to high temperatures while the diastolic pressure decreases, and frequently becomes a negative quantity.

(6) The peripheral blood vessels dilate on exposure to high temperatures.

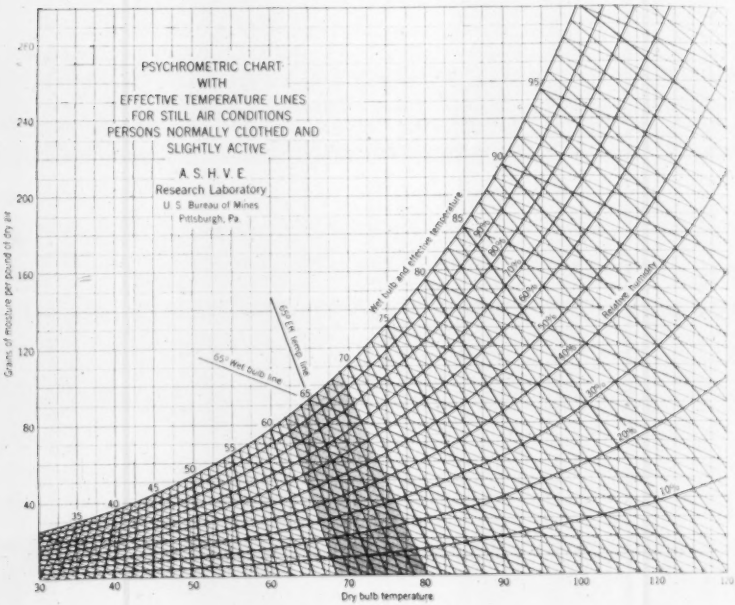

Fig. 156

(7) Respirations are increased in rate and depth after removal from a hot atmosphere to a cooler one.

(8) The loss in weight which occurs after exposure to high temperatures is not permanent.

(9) Exposure to high temperatures did not cause albuminuria in any of the subjects of these experiments.

Thousands of observations have provided data from which the accompanying comfort charts (Figs. 156 and 157), have been plotted. These data have been so carefully determined that they are beyond question. Hence we know the ranges of conditions ("Effective Temperatures") which affect human comfort.

The charts indicate, with positive authority, the "Effective Temperatures" (conditions) which result in comfort for the average person. The Effective Temperature (condition) is an experimentally determined scale (series of conditions) which, unlike either the dry-bulb or wet-bulb scales (alone), is a true measure or index of a person's feeling or sensation of warmth in all combinations of temperature, humidity and air motion.

The indoor conditions of comfort, in winter, have been briefly discussed. Those of summer are, of course, entirely different, depending, in large measure, upon the *outdoor* conditions. The dry-bulb temperature and relative humidity which result in summer comfort are higher than those of winter, due partly to acclimatization and partly to the lighter clothing customarily worn in summer. The indoor summer comfort conditions bear a definite relation to the outdoor conditions, and vary with them. This is true because the person must be protected from shock, upon entering or leaving the indoor conditions, and from the condensation of the

moisture in the air trapped between the clothing and the body, which would occur were the indoor conditions too "low" as compared with the outdoor conditions.

The relation between the most desirable mechanically maintained indoor conditions and the prevailing outdoor conditions has been definitely established by careful experiment and is as follows (the indoor conditions being maintained, of course, by means of suitable air conditioning equipment, including the necessary refrigeration)*:

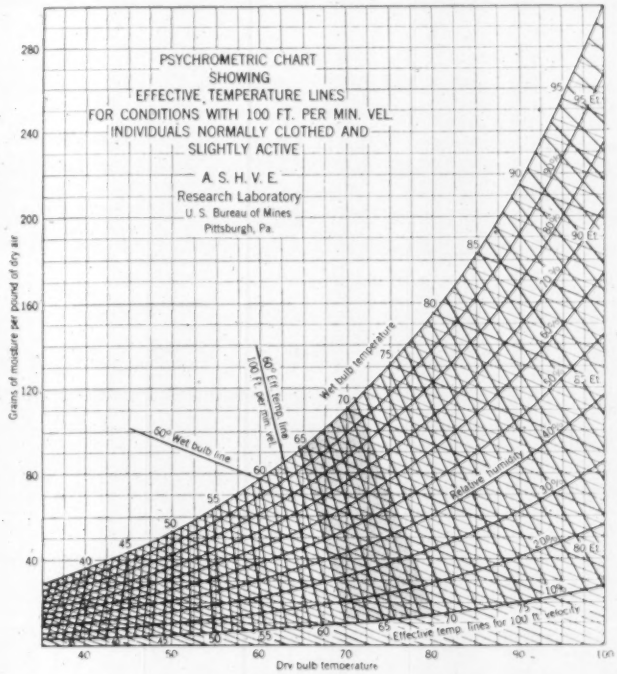

Fig. 157

Outdoors (Summer)	Indoors		
Dry-bulb °F.	Dry-bulb	Wet-bulb	Relative Humidity
95	80.0	65.2	49
90	78.0	64.5	50
85	76.5	64.0	51
80	75.0	63.5	53
75	73.5	63.0	57
70	72.0	62.5	60

These data show that although a difference of 15° between the outdoor and indoor dry-bulb temperatures is desirable under extreme outdoor conditions, this difference diminishes rapidly as the outdoor temperature falls, until at an outdoor temperature of 80° it is but 5°, one-third of the former difference. At 70° outdoor temperature, a common, though infrequent, summer condition in the northern United States, the comfortable indoor condition requires a dry-bulb temperature *higher* than that of the outdoors.

In no case is there a difference exceeding 15°, and most of the time the difference approximates but 5°, indicating the absurdity of the familiar signs declaring that it is "20° cooler inside."

Frigidity, or too great a difference between the outdoor and indoor conditions is more uncomfortable than the outdoor conditions themselves.

*Am Soc. Heat.-Vent. Engrs. Guide, 1929.

4. Measurement of Humidity

In a scientific laboratory the absolute or quantitative method of determining atmospheric humidity involves taking a unit volume of air of known pressure and temperature, extracting all of its aqueous content, weighing this water, calculating the grains per cubic foot in the original sample and thereby determining absolute humidity, relative humidity and other magnitudes.* This procedure is probably never followed in routine practice in industrial plants. It is not necessary. In the first place there are direct-reading instruments (described in the following sections, 5 and 6) which can be calibrated accurately from time to time. In the second place the laws of humidity, governing the relations of the various magnitudes—such as weight of vapor, vapor pressure, relative humidity, dry-bulb temperature, etc.—are so well established that when any two of the six principal magnitudes involved are known, any or all of the other four can be found by reference to familiar tables or charts, such as those in the Appendix.

The six magnitudes ordinarily measured or taken off charts and tables are as follows:

(1) Dry-bulb temperature
(2) Wet-bulb temperature
(3) Dew-point
(4) Relative humidity
(5) Vapor pressure (especially the deficiency in terms of vapor pressure)
(6) Absolute humidity, or "actual humidity"

In industrial practice the relative humidity is the condition of greatest importance. It is either measured directly by a hygroscopic instrument, or it is deduced from the temperatures of the air and of the wet-bulb.

The laws of humidity having been (sketchily) summed up in Section 1, this section concerns itself with the assignment of numerical values—with instrumental methods and mathematical methods of actual measurement.

Principles of Instrumental Measurement

(1) *Chemical Methods.* A measured quantity of air (known volume, pressure and temperature) is passed through tubes and chambers, one or some of which contain one or more substances which absorb moisture. Calcium chloride, sodium oxide, phosphoric anhydride, sulphuric acid and other compounds are variously employed. With some compounds the increased weight gives the exact weight of the water vapor; with others the absorption of moisture results in changes in electrical resistance or mobility of ions. We know of no industrial instrument employing these methods which are, it must be said, the only scientifically accurate ones in principle—especially where absorbed moisture is weighed.

*"MAGNITUDES"—Instruments measure or control (1) conditions, (2) properties or (3) composition. A practical term was needed to cover all these many and varied objects of measurement—to designate "that which is measured or controlled by an instrument." No such term was in use when the first instalment of this Handbook appeared last January. The term "quantity" could not be borrowed: it is only applicable in a restricted sense, and it is inapplicable to such concepts as temperature or speed, which are intensities, or to duration, liquid level, hardness, specific gravity, etc. Moreover, "quantity" already has several definite meanings. As a solution of this practical problem the author coined the expression *measurable magnitude* to take the place of "quantity" as denoting an object of measurement, and has employed it in articles. Not having received a single objection, but on the other hand observing that his term has been accepted by others, the author assumes that it is henceforth acceptable and hopes that it will generally be adopted. If anyone doubts the need of a new engineering and scientific term, let him select between "quantity" and *magnitude* as referring to temperature or to vapor pressure!

(2) *Hygroscopic Methods.* The influence of atmospheric moisture on hair, violin strings, certain woods and numerous other organic materials results in dimensional changes roughly proportional to the relative humidity. Elongation or contraction is conveniently magnified by means of pointers, etc.

(3) *Dew-point determination.* A surface is gradually cooled until moisture forms on it. The temperature of the surface is that of saturation for the water vapor actually carried by the air. Tables then give the absolute humidity. The air temperature is measured and the relative humidity obtained from tables or charts.

(4) *Psychrometry.* The relation of air temperature to wet-bulb depression in rapidly circulating air is a function of the relative humidity of the circulated air. From the readings of a dry-bulb thermometer and of a fanned or whirled wet-bulb thermometer, all other data can be computed.

It may be said that industrial psychrometry began in 1911 with Carrier's paper on the "Rational psychrometric formula" before the American Society of Mechanical Engineers. In his own words:

"The following principles underlie the entire theory of the evaporative method of moisture determination as well as of air conditioning:

"(A) *When dry air is saturated adiabatically the temperature is reduced as the absolute humidity is increased, and the decrease of sensible heat is exactly equal to the simultaneous increase in latent heat due to evaporation.*

"(B) *As the moisture content of air is increased adiabatically the temperature is reduced simultaneously until the vapor pressure corresponds to the temperature, when no further heat metamorphosis is possible. This ultimate temperature may be termed the temperature of adiabatic saturation.*

"(C) *When an insulated body of water is permitted to evaporate freely in the air, it assumes the temperature of adiabatic saturation of that air and is unaffected by convection; i. e., the true wet-bulb temperature of air is identical with its temperature of adiabatic saturation.*

"From these three fundamental principles there may be deduced a fourth:

"(D) *The true wet-bulb temperature of the air depends entirely on the total of the sensible and the latent heat and is independent of their relative proportions. In other words, the wet-bulb temperature of the air is constant, provided the total heat of the air is constant.*"

Psychrometry today implies rapid circulation. The temperature of a wet-bulb in "stagnant" air, it is now generally realized, does not mean anything. (What is "stagnant" air? Evaporation itself induces some circulation.) Psychrometry is the basic method employed in the majority of industrial humidity indicating and recording instruments.

(5) *Evaporimetry.* Method based on rate of evaporation from a given area of a given material exposed to the conditions being studied.

Descriptions of instruments, in the subsequent sections, are of course restricted to industrial forms.

Bases of Tables and Charts

There are so many ways of numerically expressing "humidity" that some confusion arises from the use of vague terms by different authorities. Several living writers are doing much to correct the looseness. In spite of their efforts and of those of a number of scientists and engineers, however, no full set of international standards has been adopted. English and metric

values of some constants, moreover, differ in the third—and even the second—significant figure. And as for symbols . . . well, let us start with a list of those employed in the basic formulas. Duplications necessitated taking some slight liberties—but not with contemporary Americans.

A_n = normal atmosphere
B = barometric pressure
C = instrumental constant
c = specific heat
c_p = specific heat at constant pressure
c_v = specific heat at constant volume
c_{ps} = specific heat of steam at constant pressure between t and t'
c_{pa} = specific heat of dry air at constant pressure, between t and t'
d = density of air, in general
d_h = density of air at h
d_0 = density of air at T_0 and A_n
d_s = density of saturated vapor at t
E = vapor pressure of saturation at t
E' = vapor pressure of saturation at t' ($> e'$ in theory, $= e'$ practically)
e = vapor pressure present ("actual")
e' = vapor pressure when in equilibrium with water at t' (by definition)
$e' - e$ = deficiency, in terms of vapor pressure, at t'
F = absolute humidity at saturation point, grams per cubic meter
= absolute humidity, grams per cubic meter
P = pressure
p = pressure
p_a = absolute air pressure
q = weight of moisture in 1 kg of moist air
R = relative humidity
r = latent heat of vaporization
r' = latent heat of vaporization at t'
S = specific weight of water vapor
T = absolute temperature, general
T_0 = absolute temperature, of ice point
T' = absolute temperature, "virtual"
T_c = critical temperature, absolute °C
t = reading of dry-bulb
t' = reading of wet-bulb
$t - t'$ = wet-bulb depression
t_c = critical temperature, °C above ice point
τ = dew point
V = specific volume of air (cubic feet per pound) at t
V_s = specific volume of saturated vapor at t
W = weight (pounds) of moisture actually mixed with one pound of dry air
W' = ditto at saturation point = Vd_s
$W' - W$ = 1. weight of moisture per pound of dry air *added* to saturate the air, in humidifying; 2. deficiency, in terms of weight, at t
w = absolute humidity, in grains per cubic foot
x = ratio (mass of vapor)/(mass of dry air

Vapor Pressure—General formula for computation of vapor pressure:

$$e' - e = CB(t - t')\times 10^{-4} \quad . \quad . \quad . \quad . \quad (1)$$

B, e and e' are expressed in the same units, which may be any desired. The variation of C with temperature is negligible but note that C is constant for any given velocity of air-flow past wet-bulb. If temperatures are expressed in °C the value of C for a properly fanned or whirled wet-bulb is 6.6.

Density of Dry Air—General formula:

$$d = \frac{0.001293}{1 + a\,t}\times\frac{p}{760} \quad . \quad . \quad . \quad . \quad (2)$$

Density of Moist Air—Relations of densities d_s of vapor and d_a of dry air at same pressure and temperature:

$$\frac{d_s}{d_a} = 0.6217; \quad \frac{d_a - d_s}{d_a} = 0.3783$$

For any pressure unit,

$$d = \frac{d_0\,T_0}{T}\left(\frac{B - 0.3783\,e}{A_n}\right) \quad . \quad . \quad . \quad (3)$$

$$= \frac{d_0\,T_0\,B}{T\,B_0}\left(\frac{0.6217(1+x)}{0.6217+x}\right) \quad . \quad . \quad . \quad (4)$$

In mm of mercury,

$$d = \frac{464.6}{10^6}\left(\frac{B - 0.3783\,e}{T}\right) \text{g/cm}^3 \quad (5)$$

$$= \frac{288.9}{10^6}\left(\frac{B(1+x)}{(0.6217+x)\,T}\right) \text{g/cm}^3 \quad (6)$$

"Actual" Humidity, English Units—Harding and Willard* state that "it simplifies calculations somewhat if the actual humidity is considered as the number of pounds of saturated vapor mixed with *one pound of dry air* when saturated at a given temperature and pressure." To find the weight of vapor per pound of dry air in a saturated mixture of air and vapor at temperature in °F abs., all pressures in pounds per square *inch*. From Dalton's law,

$$B = e' + p_a = 14.7 \text{ lb.}$$

and the saturated vapor pressure being obtained from steam tables in the same units, the partial air pressure is obtained. At 60°F, for instance, it would be $14.70 - 0.26 = 14.44$. From this value of p_a we obtain by application of the gas laws the volume of one pound of dry air at t. In this case it is 13.33 cubic feet, which is also the volume of the saturated vapor. The weight of the saturated vapor is obtained by multiplying this identical volume in cubic feet by the density in pounds per cubic feet as given in steam tables. Thus we have $13.33 \times 0.000829 = 0.01105$ lb. per lb. of dry air in the mixture. This same operation is also expressed in the

English Unit Formula for Saturated Air (Carrier)—Same symbols as in above table but values of pressures in pounds per square *foot*. Vapor and air occupying the same volume, $W = Vd_s$

$$W' = \frac{S\,e'}{B - e'} \quad (7)$$

$$W' = \frac{53.35\,(t+459)\,d_s}{B - e'} \quad (8)$$

or, when pressures are in pounds per square *inch*,

$$W' = \frac{0.378\,(t+459)\,d_s}{B - e'} \quad (9)$$

or, for weight in *grains*, pressures in *inches of mercury*,

$$G = \frac{5284\,(t+459)\,d_s}{B - e'} \quad (10)$$

which is the basis of the saturation curve in the Carrier and Bulkeley psychrometric charts.

Adiabatic Saturation of Dry Air—Assume passing dry air, initial temperature t, through spray or wick or "saturated sponge" perfectly insulated so that heat is neither supplied from nor extracted by exterior conditions. When equilibrium is reached, both water and emergent air are at t'.

$0.2411\,(t - t')$ = B.T.U. given up by 1 lb. of air

r' being latent heat of saturated vapor at t'

$r'W$ = B.T.U. required to evap. weight of moisture added

Since exchange is adiabatic

$$r'W = 0.2411\,(t - t') \quad (11)$$

*Mechanical Equipment of Buildings, Vol. I—Heating and Ventilation, by Louis A. Harding and Arthur C Willard.

Adiabatic Saturation of Moist Air—Lack of space compels omitting demonstration of the equality in this case. Harding and Willard give an interesting development, employing a heat diagram, which is recommended to air-conditioning engineers. Bongards' painstaking demonstration is also interesting in that it assumes an actual wet-bulb over which passes an air-stream, the portion of which, whose humidity is increased, may or may not correspond to the portion which is cooled; and mathematically explores every case, winding up with a triumphant proof of the equality at equilibrium. (For a popular discussion of "what happens at the wet bulb" see end of section 1, this chapter.) Carrier's original equation (English units):

$$r'(W'-W)=c_{pa}(t-t')+c_{ps}W(t-t') \qquad (12)$$

Carrier's Method—Determination of weight W of water vapor actually mixed with one *pound* of dry air at temperature t. Adiabatic action as above. $W'-W$ = weight of moisture per pound of dry air *added* in order to saturate the air. r' = latent heat of vaporization at temperature t', therefore $(W'-W)\,r'$ = heat in B.T.U. necessary to evaporate $(W'-W)$ lb. of water at t'.

Since the change is adiabatic,

$$(W'-W)\,r'=c_{ps}W(t-t')+c_{pa}(t-t')$$

Substituting the average values of c_{ps} and c_{pa}, 0.44 and 0.24 respectively

$$W=\frac{r'W'-0.24\,(t-t')}{r+0.44\,(t-t')} \qquad (13)$$

Absolute Humidity—In English units,

$$w=11.7459\frac{e}{1+0.002039\,(t-32^\circ)} \qquad (14)$$

In metric units, proceeding from relative densities of air and water vapor ($S=0.623$, not the I. C. T. datum 0.6217), the weight of 1 m³ of water vapor at p is $0.623d\times10^6$. Obtaining d from formula (2) and considering that the water vapor occupies a volume identical with that of the air but under e and not p,

$$f=10^6\times0.623\times\frac{0.001293}{1+0.00367t}\times\frac{e}{760}$$

$$f=\frac{1.06e}{1+0.00367t} \qquad (15)$$

Specific Humidity—This is neither x nor the relative humidity but the ratio (mass of vapor)/(total mass).

$$q=\frac{0.6217\,e}{B-0.3783\,e} \qquad (16)$$

According to Bongards,

$$q=0.623\frac{e}{p_a-0.377\,e} \qquad (17)$$

Deficiency—This term is used in connection with rate of evaporation. Expressed as $e'-e$ or $W'-W$ or as quantity of water lacking to saturate 1 m³ of air with water vapor. These two latter are somewhat ambiguous, as Bongards points out, because $E-e$ has a value different from $e'-e$.

Example. At 14°C and 25% relative humidity $e = 3$ mm and $E = 12$ mm. At a circulation of 2 m per second a moist material is cooled about 6°C and above the material $e' = 7$ mm. Rate of evaporation depends on the existing difference $e' - e$ or $7 - 3 = 4$ mm which is the working deficiency while the deficiency at t would be $E - e$ or $12 - 3 = 9$ mm.

Moisture-absorbing Capacity of Air

$$(W' - W) = \frac{(c_{pa} + c_{ps} W)(t - t')}{r'} \qquad (18)$$

Relative Humidity

$$R = \frac{e}{E} \qquad (19)$$

$$R = \frac{W'}{W} \qquad (20)$$

Relative Saturation—Term used by Grossman and other German writers to designate $E' - e$, which would appear to be a mere academic distinction from $e' - e$.

"*Richesse Hygrométrique*"—Term used by French writers on humidity and air conditioning, especially in connection with the evaporating (or moistening) power of air. Not the relative humidity, though the initials are the same. Bears close relation to "specific humidity" and appears to be identical with "actual humidity" or with Carrier's *W*. Defined as "the relation between the weight of water vapor and the weight of the dry air in the same volume or the same mass of moist air." As given by Bongards,

$$\text{"rh"} = 0.0623 \frac{e}{p - e} \qquad (21)$$

but as long as international standards are incomplete, the present author offers the more general expression

$$\text{"rh"} = \frac{S\,e}{p_a - e} \qquad (22)$$

which permits greater latitude in experimental determinations and in referring to one's favorite tables.

The actual weight of water vapor being a small magnitude compared with that of the dry air occupying the same volume at ordinary barometric pressures, the discrepancy is negligible. In industrial work it would be (*at its greatest value*) the difference between a "specific humidity" of 2/102 = 0.0198 and an "actual humidity" or "richesse hygrométrique" of 2/100 = 0.0200, or 0.0002.

General Psychrometric Formulas

$$e = E' - \frac{B\,c_{pa}}{S\,r'}(t - t')\left(1 + \frac{a}{\sqrt[4]{v^3}}\right)\left(1 + \frac{e\,S\,c_{ps}}{(B - e)\,c_{pa}}\right)\left(1 - \frac{e}{B}\right) \qquad (23)$$

$$e = E' - A_{o(t=\infty)}\,B\,(t - t')\,\frac{1}{r}\left(1 + \frac{a}{\sqrt[4]{v^3}}\right) \qquad (24)$$

These necessarily involve several instrumental and other constants. *S*, for example, represents the relation of the density of vapor and dry air at same pressure and temperature, and is used instead of the value 0.6217 because one must accept the value given by which-

ever authority one is following, and whose other values correspond. The determinations of several constants and relations by various investigators are tabulated on page 151, and values of log $1/\tau$ on page 147, of *Feuchtigkeits-Messung*.

The "U. S." Psychometric Formula—First developed by Regnault in 1845, modified and adapted to English units by Ferrel (Annual Report of Chief Signal Officer, U. S. A., 1886). Basis of Smithsonian and other U. S. tables giving value of e in inches of mercury for readings of t and t' in °F on sling psychrometer.

$$e = e' - 0.000367B(t-t')\left(1+\frac{t'-32}{1571}\right) \quad . \quad . \quad (25)$$

Rational Psychrometric Formulas—As far back as 1903 Carrier had observed that the wet-bulb temperature given in the U. S. psychrometric tables agreed with the computed temperatures at which air of a known temperature and vapor content would become saturated adiabatically. In his 1911 paper he called Ferrel's formula empirical and proposed to substitute "a rational one, having a thermodynamic basis, that is, a formula depending upon the transformation of sensible heat into latent heat in the adiabatic saturation of dry air."

We omit the first Carrier formula for the value of e since he follows it by remarks pointing out that the value of $-e\,(S_1c_{ps}-c_{pa})(t-t')$ is negligible, as is also the difference between $S'r'$ and $S'r'+(S_1c_{ps}-c_{pa})\,(t-t')$ so that the equation

$$e = e' - \frac{c_{pa}\,(B-e')\,(t-t')}{S'r'}$$

is obtained. Substituting values for r', S' and c_{pa},

$$e = e' - \frac{(B-e')\,(t-t')}{2803-1.329t}$$

But the coefficient $1/(2800-1.3t)$ being permissible,

$$e = e' - \frac{(B-e')\,(t-t')}{2800-1.3t} \quad . \quad . \quad . \quad . \quad (26)$$

This formula is for the exact wet-bulb temperature obtained by the aspiration psychrometer. With sling psychrometers a correction must be made for error in depression due to radiation and stem correction. For the sling psychrometer

$$e = e' - \frac{(B-e')(t-t')}{2755-1.28t'} \quad . \quad . \quad . \quad . \quad (27)$$

Psychrometric formulas, embodying B, show that barometric pressure affects the value of e and hence the relation $100e/E$ which is the relative humidity. The maximum possible error near sea level is less than 1% in the determination of relative humidity, so that various psychrometric charts, based on 29.92 or 30 inches or other barometric pressures close to standard, agree with one another very closely.

Measurement Practice

As explained above, the practical measurement of humidity in industry consists of either

(1) Observation of the readings or records of hygroscopic instruments, or

(2) Application of psychrometry—working from the readings of dry-bulb and wet-bulb thermometers (generally alone, sometimes supplemented by the dew-point apparatus or a hygroscopic instrument) and using the tables and charts. (It goes without saying that in order to avoid errors

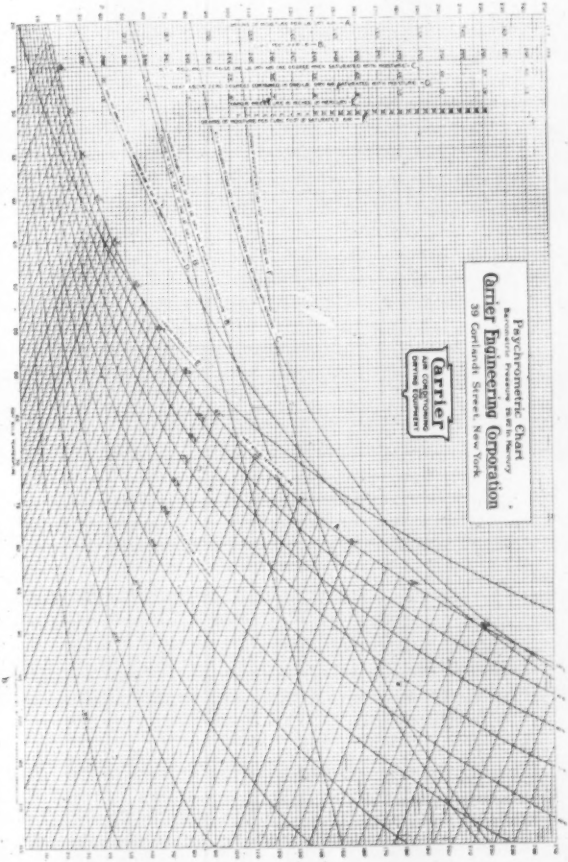

Fig. 153

in humidity determinations one must avoid errors in temperature measurement. Hence the necessity for using none but accurate psychrometers, and handling them properly. For this subject see the next section, Indicating Instruments.)

Several important tables and charts are included in the Appendix, with their authoritative sources duly noted. It is not amiss to reproduce in small size, here in the text, the Carrier and the Bulkeley Psychrometric Charts which are American industrial standards. The former was brought out in 1911 and immediately won acceptance. In the course of years of

use by thousands of engineers, it was natural that modifications and improvements should be suggested. After fifteen years—in 1926—the Bulkeley Chart was presented before the American Society of Heating and Ventilating Engineers and was adopted as the standard of that Society, with the support of Mr. Carrier who stated that it was the equivalent of three charts and that by reason of the logarithmic scale the accuracy at each end was compatible with the accuracy at the center.

In the Bulkeley Chart (see reduced fac-simile, Fig. 159) which is based on the Carrier psychrometric formula, vapor pressures at different temperatures are plotted on the vertical ordinate in mm of mercury to logarithmic scale. The saturation line is the upper diagonal straight line running lower left and upper right hand corners of the chart. The relative humidity lines are those parallel to and below the saturation line. All vertical lines on the chart are dry-bulb temperatures. All horizontal lines to the right of saturation line are dew-point temperatures. Equivalent centigrade temperatures are conveniently given at bottom and right side of chart. The wet-bulb lines are those curving downward to right of saturation line.

The directrix curves above the saturation line are as follows:

"A" is the total heat in BTU contained in the mixture above 0°F and is to be referred to column of figures at left of chart. The hook at 32°F is due to the latent heat of fusion.

"B" is grains of moisture or water vapor contained in each pound of the saturated mixture and is to be referred to figures at left side of chart.

"C" is grains of moisture or water vapor per cubic foot of saturated mixture and is to be referred to figures at left side of chart and divided by ten.

"D" is weight in decimal fractions of a pound, of one cubic foot of the saturated mixture, and is to be referred to the first column of figures to the right of the saturation line between vertical dry-bulb temperature lines 170 and 180°. The relative density of the mixture is in similar manner read from the same curve by the column of figures between the vertical dry-bulb lines 180 and 190°.

"E" is similar to "D" but is for dry air devoid of all moisture or water vapor. For convenience the approximate absolute temperature of 500°F is given at 40°F on the saturation line for the purpose of calculating volume, weight per cubic foot and relative density at partial saturation.

The following instructions for the use of the ever-popular Carrier Chart have been supplied by the Carrier Engineering Corporation.*

Example 1—*Given:* Dry Bulb Temperature, 70°; Wet Bulb Temperature, 60°. Find the Percentage Relative Humidity and the Dew Point.

Locate point of intersection of vertical line representing 70° Dry Bulb Temperature with the oblique line representing 60° Wet Bulb Temperature. By interpolation this point indicates the percentage of Relative Humidity as 56 per cent and by following the intersecting horizontal line to the left to its intersection with Curve A, the Dew Point is indicated as 53.4°.

Example 2—*Given:* Dry Bulb Temperature, 80°; Relative Humidity, 59 per cent. Find the Dew Point and Wet Bulb Temperature.

Locate the point of intersection of the vertical line representing 80° Dry Bulb Temperature with the interpolated position of the curved line which would represent 59 per cent Relative Humidity. Reading horizontally to the left from this point, to Curve A, the Dew Point is indicated as 64°, and reading obliquely upward to the left, between the Wet Bulb lines, to Curve A, the Wet Bulb Temperature is indicated as 69.3°.

Example 3—*Given:* Dry Bulb Temperature, 75°; Dew Point Temperature, 55°. Find Percentage Relative Humidity and Wet Bulb Temperature.

Locate the point of intersection of the vertical line representing 75° Dry Bulb Temperature with the horizontal Dew Point line intersecting Curve A at 55°. This point indicates the Relative Humidity as 50 per cent, and by interpolation the Wet Bulb Temperature as 62.6°.

Example 4—*Given:* Relative Humidity, 50 per cent; Wet Bulb Temperature, 60°. Find Dry Bulb Temperature and Dew Point.

Locate the point of intersection of the curved line representing 50 per cent Relative Humidity with the oblique line representing 60° Wet Bulb Temperature. Reading vertically downward from this point to the Dry Bulb Temperature Scale, the Dry Bulb Temperature

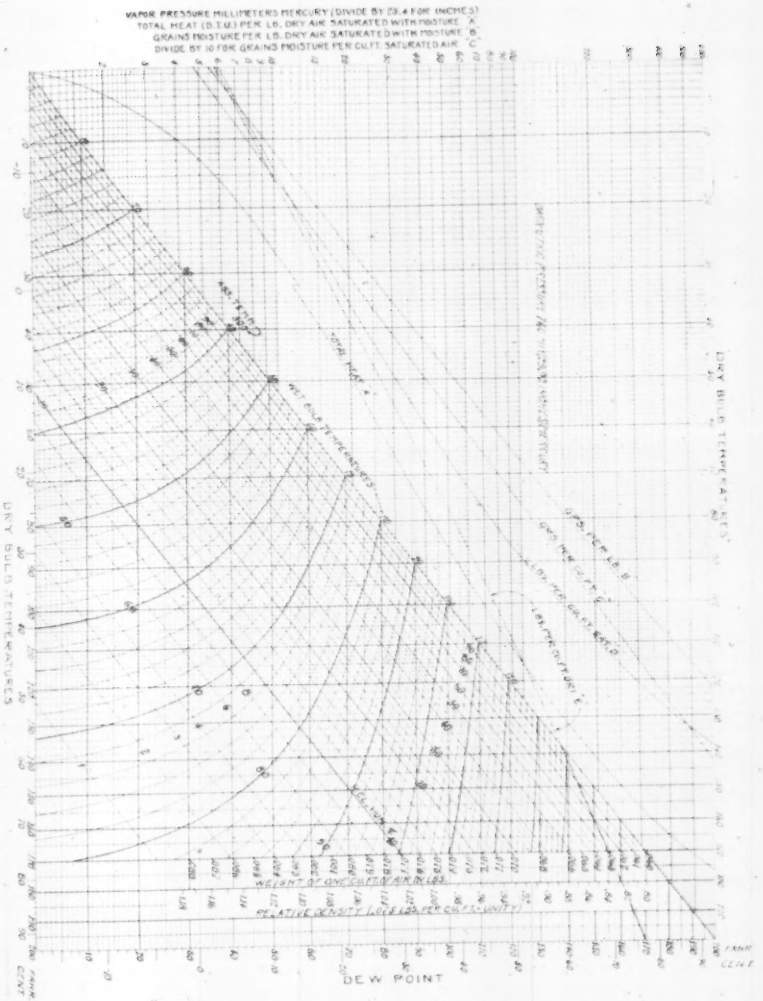
VAPOR PRESSURE MILLIMETERS MERCURY (DIVIDE BY 25.4 FOR INCHES)
TOTAL HEAT (B.T.U.) PER LB. DRY AIR SATURATED WITH MOISTURE A
GRAINS MOISTURE PER LB. DRY AIR SATURATED WITH MOISTURE B
DIVIDE BY 10 FOR GRAINS MOISTURE PER CU.FT. SATURATED AIR C
DEW POINT
DRY BULB TEMPERATURES
WEIGHT OF ONE CUBIC FOOT AIR IN LBS.
RELATIVE HUMIDITY LINES IN PER CENT

Fig. 159. Bulkeley Psychrometric Chart. © Am. Soc. Heat. Vent. Engrs.

is indicated as 71.8°, and, reading horizontally to the left to Curve A, the Dew Point is indicated as 52°.

Example 5—*Given*: Wet Bulb Temperature, 55°; Dew Point, 50°. Find Dry Bulb Temperature and Relative Humidity.

Locate the point of intersection of the oblique line representing 55° Wet Bulb Temperature with the horizontal line representing the Dew Point of 50°. Reading vertically downward from this point to the Dry Bulb Temperature Scale, the Dry Bulb Temperature is indicated as 61.5°, and by interpolation, the Relative Humidity is indicated as 67 per cent.

Example 6—*Given*: Relative Humidity, 40 per cent; Dew Point, 40°. Find Dry Bulb Temperature and Wet Bulb Temperature.

*These excellent instructions constitute a little manualet practical psychrometry and are reproduced without editing (except tEx. 13 shortened). Hence the discrepancies between its terms and forms, and the author's.

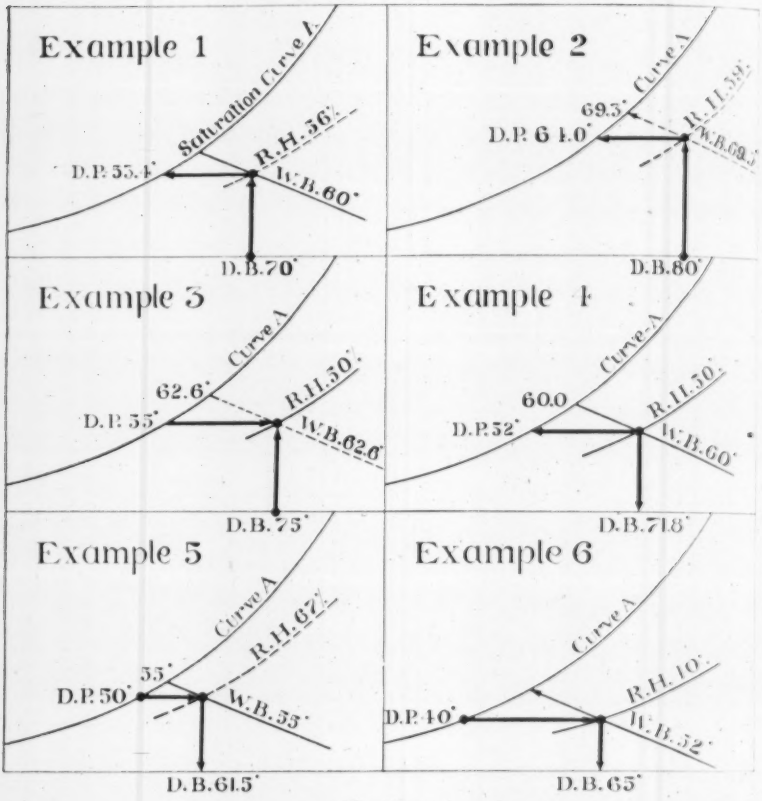

Fig. 160

Locate the point of intersection of the curved line representing 40 per cent Relative Humidity with the horizontal line intersecting Curve A at 40° Dew Point Temperature. Reading vertically downward from this point to the Dry Bulb Temperature Scale, the Dry Bulb Temperature is indicated as 65°, and reading obliquely upward to the left, along the Wet Bulb lines, to Curve A, the Wet Bulb Temperature is indicated as 52°.

Example 7—*Given:* Dew Point, 70°; and Dry Bulb, 80°. Find the Relative Humidity if the Dry Bulb Temperature is increased to 90°, the Dew Point Temperature remaining constant.

Locate intersection of vertical 80° Dry Bulb line, with horizontal 70° Dew Point line. From this point read horizontally to the right to the vertical 90° Dry Bulb line and at this intersection interpolate for the percentage of Relative Humidity which is indicated as 52 per cent.

Example 8—*Given:* Dry Bulb Temperature, 70°; Wet Bulb Temperature, 60°. Find the resulting Relative Humidity when air is heated to 80° (Dry Bulb Temperature), without increase in moisture content.

Locate the point of intersection of vertical 70° Dry Bulb with the oblique 60° Wet Bulb line which indicates an existing humidity of 56 per cent. Reading horizontally to the right from this point to the intersection with the vertical 80° Dry Bulb line the resulting Relative Humidity is indicated as 40 per cent.

Example 9—*Given:* Dry Bulb Temperature, 80°; Wet Bulb Temperature, 70°. Find the Vapor Pressure.

Find the point of intersection of the vertical 80° Dry Bulb line with the oblique 70° Wet Bulb line. From this point read horizontally to the left, to Curve A. (Dew Point is indicated on this scale as 65.3°.) From this second point read vertically to Curve D. From

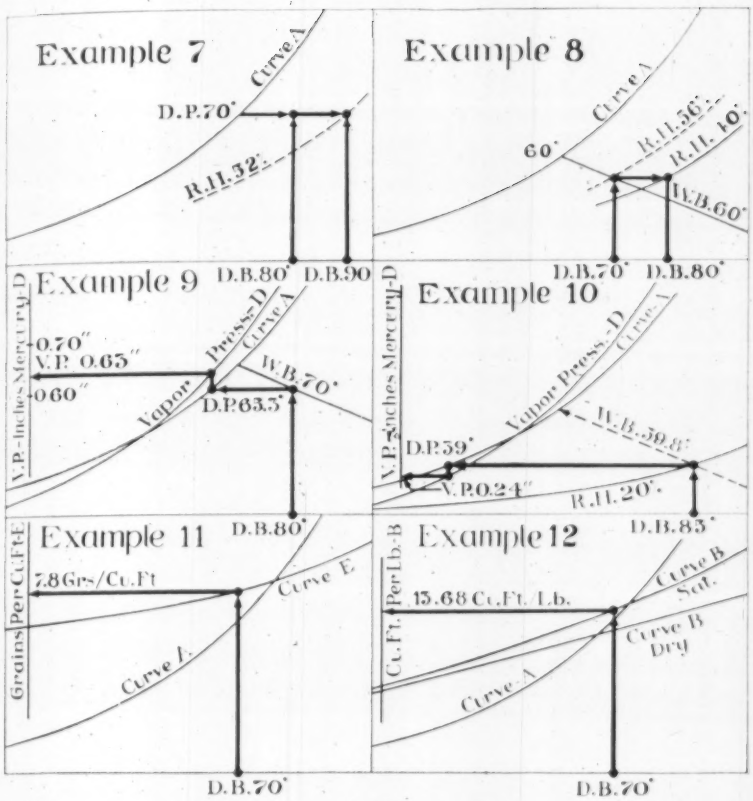

Fig. 161

the vertical intersection with Curve D, read horizontally to the left to Scale D, where the Vapor Pressure is indicated as 0.63 inches of Mercury.

Example 10—*Given:* Relative Humidity, 20 per cent; Dry Bulb Temperature, 85°. Find Wet Bulb Temperature, Dew Point Temperature and Vapor Pressure.

Locate intersection of the curved line representing 20 per cent Relative Humidity with the vertical 85° Dry Bulb line. By interpolation between the oblique Wet Bulb lines this point is found to indicate a Wet Bulb Temperature of 59.8°. From this point read horizontally to Curve A on the left where a Dew Point of 39° is indicated. From 39° on Curve A, read vertically downward to Vapor Pressure, Curve D, thence horizontally to the left to Scale D—*Vapor Pressure in Inches of Mercury* where a vapor pressure of 0.24 inches of Mercury is indicated.

Example 11—*Given:* Air at Dry Bulb Temperature of 70°. Find Grains of Moisture per Cubic Foot of Air when Saturated at this Temperature.

Follow vertically the 70° Dry Bulb line to Curve E—*Grains of Moisture per Cubic Foot of Saturated Air.* From this intersection follow horizontally left to Scale E, where 7.8 grains per cubic foot is indicated.

Example 12—*Given:* Air at 70° Saturated with Moisture. Find Volume in Cubic Feet per Pound.

Follow vertically the 70° Dry Bulb line to the upper Curve B—*Volume in Cubic Feet of One Pound of Dry* Air Saturated with Moisture.* From this intersection follow horizontally left to Scale B, where 13.68 cubic feet per pound is indicated. Note that the lower Curve B—is the *Volume in cubic feet of one pound of dry* air absolutely free of water-vapor.* This curve is also to be referred to Scale B on the left.

*Dry Air—free from any floating particles of condensed liquid—fog.

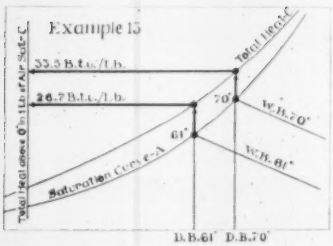

Fig. 162

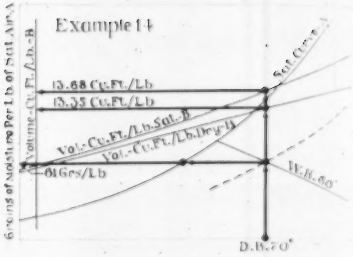

Fig. 163

Total Heat—*Procedure used in engineering calculations to ascertain the heat to be removed or added in cooling or heating air from one condition to another.*

(*The Total Heat of Air* is composed of the sensible heat of the air, and the latent heat of the moisture or vapor in the air. The Total Heat is constant for any given Wet Bulb Temperature, irrespective of any change in the Dry Bulb Temperature. In the chart, the Total Heat is shown, for the sake of convenience, as above zero degree Fahrenheit. Total Heat, as here used, does not include the sensible heat of the liquid nor the latent heat of fusion. It is assumed that the water evaporated is initially at the Wet Bulb Temperature).

Example 13—Having Air at a Wet Bulb Temperature of 70° and Air at a Wet Bulb Temperature of 61°, find the *difference* in Total Heat between a mixture containing one pound of dry air and the quantity of moisture present at the Wet Bulb Temperature of 70°, and a mixture containing one pound of dry air and the quantity of moisture present at the Wet Bulb Temperature of 61°.

The quantity of moisture present at any given Wet Bulb Temperature will, of course, vary with the existing Dry Bulb Temperature. Since the Total Heat is a function of the Wet Bulb Temperature, irrespective of the Dry Bulb Temperature, the quantity of moisture present does not affect the Total Heat so long as the Wet Bulb Temperature does not change. Note that this Chart deals with a mixture containing one pound of dry air *plus* the amount of moisture present under the given conditions. In no instance does the Chart contemplate a pound of mixture (air and moisture together), but always a mixture containing one pound of dry air. Find the intersection of the 70° oblique Wet Bulb line with Curve A. From here read vertically upward to the Curve C. From this intersection read horizontally to the left to the Scale C, which indicates the Total Heat (above 0°F.) as 33.5 B.t.u. Repeat this procedure to ascertain the Total Heat at the Wet Bulb Temperature of 61°, which is indicated as 26.7 B.t.u. Then, subtracting, 33.5—26.7=6.8 B.t.u., which is the difference in Total Heat.

Absolute Humidity of Partially Saturated Air, Expressed in Grains per Cubic Foot.

Example 14—*Given*: Dry Bulb Temperature, 70°; Wet Bulb Temperature, 60°. Find the Absolute Humidity (Grains of Moisture per Cubic Foot).

Locate point of intersection of 70° Dry Bulb line with 60° Wet Bulb line, and from this point read horizontally to the left to the Scale A, where the number of grains in the mixture containing one pound of dry air is indicated as 61. Then locate the points of intersection of the vertical 70° Dry Bulb line with the two curves B, and from these read horizontally to the left to the Scale B.

13.68 Cu. Ft.—Volume of mixture containing one pound of dry air and sufficient moisture to saturate such air when at 70°.

13.35 Cu. Ft.—Volume of one pound of dry air.

0.33 Cu. Ft.—Increased volume of the mixture due to the presence of the moisture at 100 per cent Relative Humidity.

(In instances where the air is *saturated* or *completely free of moisture*, its volume may be found directly by locating the point of intersection of the vertical Dry Bulb line with the corresponding Curve B and referring to the Scale B.)

The percentage of Relative Humidity for air under the given conditions is indicated at the intersection of the 70° Dry with the 60° Wet Bulb line as 57 per cent. Fifty-seven per cent of 0.33 is 0.19 cubic feet, which is the increase in volume of the mixture due to the presence of the moisture in the air at 57 per cent Relative Humidity.

13.35 Cu. Ft.—Volume of dry air.

0.19 Cu. Ft.—Increased volume of the mixture due to the presence of the moisture in the given air at 57 per cent Relative Humidity.

13.54 Cu. Ft.—Volume of the given mixture containing one pound of dry air.

$$\frac{\text{61 grains per pound of dry air}}{\text{13.54 Cu. Ft. of given mixture per pound of dry air}} = 4.50 \text{ grains of moisture per cu. ft.}$$

Measurements

Industrial & Scientific

An Instruction Book for Engineers

DR. WALTER BLOCK

Eichungsdirektor der Provinz Ostpreussen

CHAPTER VII. MEASUREMENT OF AREAS

THE great majority of cases of measurement of areas involve simple shapes the linear dimensions of which are determined, after which the area is then calculated by plain arithmetic. No need to explain this procedure in detail; one may refer to the mathematical tables in which the respective formulas for the calculation of areas can be found. Irregular shapes, however, present difficulties in area measurement. A simple method which gives fairly correct values when employed carefully, consists in cutting out the area to be determined and weighing it, and then cutting a standard area of the same uniform material and also weighing it. The ratio of the two weighings then gives directly the required area, if one can be sure that both areas are of the same material. A better procedure is to draw a grid of squares over the area to be evaluated and obtain the result by counting the number of whole squares covering the area and estimating the fractions. Instead of this tedious drawing of squares it is still better to use a cross-ruled glass plate. An analogous method which is sometimes more convenient, is to divide the area, graphically or with a glass plate placed over it, into very small strips. The length of each is measured, after which the total length of all stripes is multiplied by the width of the stripe.

All these problems come up occasionally. Of greater importance, however, are the evaluation of recorded curves and the determination of areas by means of planimeters. The most frequent examples in industry are chart records. A recording apparatus, for instance, records on a paper chart the load of a machine or the output in kilowatts supplied by it. The distance of the pen from the zero line on the moving paper chart is a measure, which can be read from the scale of the recording instrument, of the output of the machine at any moment. The paper chart, driven by a clock, moves uniformly. It is, therefore, possible to read on the chart, for any particular moment, both the time and the load of the machine. It follows then that the area on the paper chart between zero line and the recorded curve is a measure of the energy consumed or supplied by the machine, for instance that amount in kilowatt-hours which must be paid if the machine supplies useful energy. The advantage of such application over an electric meter which, of course, does the same, lies in the fact that there is obtained in this way not only the total energy but also a record of the consumption of energy at different times. It is, however, necessary to determine the area between the zero line and the recorded curve when the recording instrument does not also include an integrating or kilowatt hour device.

Such measurements of instrument chart areas are made by planimeters of which there are two principal types, the polar planimeter and the coordinate planimeter. The former more usual and flexible type will be discussed first (Fig. 30). A rigid arm P turns around a fixed pole p which

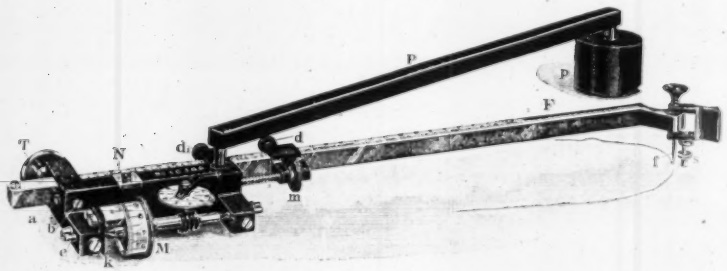

Fig 30. Compensation Planimeter

generally consists of a pin point inserted into the drawing plane; arm P carries on its other end a link to which is connected a movable and rotatable second arm F which carries at its free end the so-called guide pin f with which the area to be evaluated is circumscribed. Near the fixed end of arm F, either in its extension or parallel to it, is located the axis of a little measuring wheel M which has divisions on its circumference and is connected to a small counter to enable one to read the number of whole revolutions. If an area, such as that of a geographical map, is to be evaluated, the pole is placed on a suitable point so that the guide-pin can easily circumscribe the perimeter of the area. If this is done the measuring wheel will perform a combination of rolling and gliding movements, and the difference of its readings, before and after completely going around once, is a measure of the area. This follows from the following mathematical considerations:

In Fig. 31 we designate the length of the circumscribing arm of the planimeter by l, that of the polar arm by r, and that of the arm of the roller by ρ. If the pole is placed within the area of the surface to be measured we can easily see if we lead the guide pin completely over the circumference of the area that the latter is completely covered by the polar arm and circumscribing arm. The former covers the circle πr^2, the latter the remainder of the figure

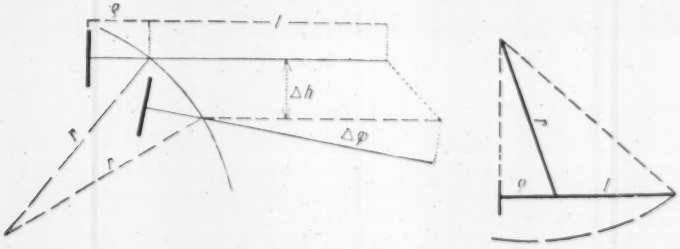

Fig 31. Theory of Planimeter

The surface of the figure is $\mathfrak{Q} = \Sigma\ \Delta q + \pi r^2$, where Δq is the small area over which the circumscribing arm passes at reduced motion. In a similar manner it can be seen that if the pole is placed outside of the figure to be evaluated, $\mathfrak{Q} = \Sigma\ \Delta q$. The circumscribing arm in passing over an element of area performs two motions, one of parallel displacement Δh and one of rotation $\Delta \varphi$. It follows therefore, that $\Delta q = l\ \Delta h + \frac{l^2}{2}\ \Delta \varphi$. A point of

the circumference of the wheel will then pass through a distance $\Delta u = \Delta h - \rho \Delta \varphi$ from which it follows that $\Delta q = l \Delta u + \left(\frac{l^2}{2} + l\rho\right) \Delta \varphi$.

and $\Sigma \Delta q = l \Sigma \Delta u + \left(\frac{l^2}{2} + l\rho\right) \Sigma \Delta \varphi$.

If the pole is outside the area, $\Sigma \Delta \varphi = 0$, therefore $\Sigma \Delta q = Q = l u$. The area is, therefore, the product of length of the circumscribing arm and the revolution of the disc. If the pole inside the circumscribing arm describes a complete circle, therefore $\Sigma \Delta \varphi = 2\pi$ and

$$Q = \Sigma \Delta q + \pi r^2 = l u + (l^2 + 2 l \rho) \pi + \pi r^2 = l u + \text{constant}.$$

The value of the constant can be found by a simple consideration of the diagram on the right of Fig. 31. If the guide pin describes a circle around the pole so that the vertical in the center of the wheel on the circumscribing arm passes through the pole the disc does not perform any rotating motion. The area of this "basic circle" is therefore given by the planimeter as zero. The Radius R of this circle is determined by $R^2 = (l + \rho)^2 + r^2 - \rho^2 = l^2 + 2 l \rho + r^2$. From this it follows that, with the pole inside, the area read on the disc must be increased by the area of the basic circle. The result of the theory is, therefore, remarkably simple.

The area of the basic circle must be determined for every planimeter separately as it is an individual constant which depends also on the changes of the length of the arms. This can be done by measuring, with the pole inside, a circle of known diameter (most suitably with the pole in its center), which is as nearly as possible equal to the basic circle.

The size of the basic circle is, by the way, given for all planimeters with fixed length of circumscribing arm, just as it is indicated what one revolution of the measuring wheel corresponds to. This measuring wheel must be handled with the greatest care as its circumference, which naturally is the only determining factor for its precision, has microscopic corrugations in order to facilitate smooth rolling and gliding.

There exists a still better type of polar planimeter, the so-called compensated planimeter. If the axis of the measuring wheel of the planimeter is not exactly parallel to the axis of the circumscribing arm (which is very difficult to obtain mechanically) certain errors occur which can be eliminated by a double measurement. This is obtained by twice circumscribing the figure to be measured, while the measuring wheel remains at the right and at the left respectively of the line pole-cricumscribing pin. Those planimeters which permit this are designated as compensated planimeters.

The coordinate planimeter operates a little differently. It consists principally of a circumscribing arm with measuring wheel and a guiding pin which permits one end of the circumscribing arm to be moved in a straight line, the coordinate axis. It is evident that if such planimeter is moved so that the circumscribing pin moves also in this line, the measuring wheel as it is moved perpendicularly to its plane can only perform gliding motions without rotations; and that similarly, if the arm is exactly at right angles to this direction and moved parallel to itself (which practically of course is impossible), the measuring wheel then rotates only without gliding; and in intermediate positions performs a combination of gliding and rotating motions. It is, therefore, obvious that the rotating motion of the wheel, which alone is measured, depends on the length of the movement of the guide-pin in the coordinate axis and on the distance of the pin from the latter. It will, therefore, be clear without further proof how a measurement of area is performed in this manner.

The accuracy of measurement of areas with planimeters is fairly great and can, in general, be assumed on an average to be a few tenths of a percent. The checking of the accuracy of a planimeter is comparatively easy

by drawing certain simple figures, measuring their area with a good scale, and comparing the results with the indications of the planimeter. Usually a check-rule is supplied by the manufacturer together with the planimeter, which permits in a simple manner to evaluate circles which are fixed on the rule by marks and the area of which is determined once for all. It is then only necessary to fasten the check-rule by its needle pole, to insert the guide-pin of the planimeter into one of the marks, and then to describe a full circle with the planimeter. In this way a definite known area has been circumscribed, and the indication of the planimeter can be checked with it, which is especially necessary if the planimeter has an adjustable length of the circumscribing arm. When measuring areas on paper one must sometimes not expect too much with regard to results as the dimensions of paper, particularly of inferior qualities are not inconsiderably influenced by changes in humidity so that a greater accuracy than 1% can hardly be expected.

The Bailey Meter Company of Cleveland, Ohio, Manufacturers of Power Plant Metering Equipment, Automatic Combustion Control and Feed Water Regulators, announces that the rapid growth of its business in and about Denver, Colorado, has necessitated the opening of a branch office in that City. Mr. M. E. Reddick has been appointed Manager of this Branch Office, which is located at 2370 Dahlia Avenue.

INSTRUMENTS BOOK SHELF

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CONDENSED CHEMICAL DICTIONARY. Compiled and edited by the Editorial Staff of the Engineering Catalog Company. *F. M. Turner, editor.* Second edition, completely revised and enlarged under supervision of T. C. Gregory, editor, and Isabelle M. Welch, assistant editor. Chemical Catalog Co., New York, 1930. Cloth, 6¼ x 9½ inches, 451 pages. Price $10.00.

The editors of the Condensed Chemical Dictionary, Second edition, have brought together a great many facts in a manner useable to the laymen as well as to the technical man. The natural inaccuracies and omissions of the older edition have evidently been thoroughly corrected. The new edition has included a great many new headings and more information in the same bulk by using smaller type.

This work should be useful to the engineering and technical organizations as a quick reference on chemical properties, methods of manufacture, grades, transportation and uses of chemical substances. The new headings include useful descriptions of such common materials as "varnish," "galvanized iron" and "soap" as well as a complete range of common and unusual chemicals. It should be valuable as an introduction and guide to more detailed study of special chemical problems and in many cases furnishes quite complete information where detail is unnecessary.

The writers have found this dictionary useful as a reference in special chemical fields outside their own experience. Judging by the data given on their own fields of experience the user need be little afraid of being misled by assuming accuracy in the facts given.—R. J. McKay and H. E. Searle.

Measurement of Air Flow

E. OWER, B.Sc. (LOND.), HONS.I., A.C.G.I.
Bramwell Medallist; Member of the Institution of Heating and Ventilating Engineers; Assistant in the Aerodynamics Department, National Physical Laboratory

CHAPTER VI (Cont'd)

Coefficients of Orifices.—In view of these variations of pressure along the pipe in the neighbourhood of the orifice, and of the fact that the pressure distribution, even if accurately determined for one set of conditions would not necessarily hold for others, it appears advisable always to measure the pressures as closely as possible to the upstream and downstream planes of the orifice plate, and this course has been adopted by J. L. Hodgson in England and by Jakob and Kretschmer in Germany. The researches of Hodgson * are of great practical value. Recognising the amount of variation that was to be expected in α with change of shape of the orifice, he concentrated on the form of sharp-edged orifice shown in Fig. 26, which is reproduced from *Engineering* for 7th March, 1924. The pressure connections will be seen to be close to the planes of the plate, and the general proportions of the orifice are as shown in the figure.

Hodgson determined the coefficients of such orifices under various conditions and with a variety of compressible and incompressible fluids, and found that certain general conclusions could be drawn. In discussing these results we may refer to equation (10), which indicates the variables upon which α may be expected to depend. The effect of one variable alone may be determined by experiments in which the other two are kept constant. In the first place, Hodgson found that, when testing for the variation of α with $\frac{v_2 d_2}{\nu_2}$ at constant values of $\frac{d_2}{d_1}$ and $(\beta)\frac{p_2}{p_1}$, a wide variation of $\frac{v_2 d_2}{\nu_2}$ was possible without causing a change in α. He states that the curve of α against $\frac{v_2 d_2}{\nu_2}$, when the other variables do not change, is a horizontal straight line within the range of values of $\frac{v_2 d_2}{\nu_2}$ of about 16,000 to 1,600,000,

* *Proc. Inst. C.E.*, vol. cciv., 1916-17, Part II., and vol. ccx., p. 272. See also *Trans. Inst. Naval Architects*, vol. lxiv., 1922, p. 189; *Engineering*, 7th March, 1924, p. 314; *Inst. Civil Engineers, Selected Engineering Papers*, No. 31, 1925.

which, fortunately, covers the very large majority of cases that are likely to occur in practice. It appears, therefore, that the variation of α with $\frac{v_2 d_2}{\nu_2}$ can nearly always be neglected. Exceptions occur for the extreme cases of slow flow through small orifices or rapid flow through large orifices.

For all except abnormal conditions, it is necessary, therefore, only to consider the effect of changes in $(\beta)\frac{p_2}{p_1}$ and $\frac{d_2}{d_1}$, and, if we confine our attention to air flow, a further simplification is possible, since the variable $(\beta)\frac{p_2}{p_1}$, which is a function of both γ and the expansion ratio, can be replaced by the variable $\frac{p_2}{p_1}$. The complete variable $(\beta)\frac{p_2}{p_1}$ need only be considered in comparisons of values of α for different gases; for any one gas γ is constant and may therefore be neglected.

Thus, for air flows within the range of $\frac{v_2 d_2}{\nu_2}$ of 16,000 to 1,600,000, the discharge coefficient for Hodgson's orifices would appear to depend only upon $\frac{p_2}{p_1}$ and $\frac{d_2}{d_1}$. The variation with $\frac{p_2}{p_1}$ for constant values of $\frac{d_2}{d_1}$ is stated by Hodgson to be approximately linear; he found further, that at a constant value of $\frac{p_2}{p_1}$, α had a constant value for all values of $\frac{d_2}{d_1}$ less than 0·7, so that provided $\frac{d_2}{d_1}$ is always made less than 0·7 its influence in modifying the value of α may be neglected, and only one variable, viz. $\frac{p_2}{p_1}$, remains to be considered for nearly all cases of air flow. Hodgson found that the variation of α with $\frac{p_2}{p_1}$ was approximately expressible in the form

$$\alpha = 0{\cdot}914 - 0{\cdot}306\frac{p_2}{p_1}. \quad . \quad . \quad . \quad (13)$$

In a large number of cases $\frac{p_2}{p_1}$ will be found to be between 0·98 and 1·00, and for these conditions α may be taken as 0·61.

Similar results for values of $\frac{p_2}{p_1}$ near unity have been obtained for sharp-edged orifices very similar to those of Hodgson by Jakob and Kretschmer.* Here again the upstream and

* *Regeln für Leistungsversuche an Ventilatoren und Kompressoren*, 1925, p. 16, published by the Verein Deutscher Ingenieure, Berlin.

downstream pressures were measured close to the orifice plate. These tests covered a range of $\frac{v_1 d_1}{\nu_1}$ of 20,000 to 500,000, where v_1 was here taken as the mean velocity in the pipe in which the orifices were installed, and d_1 and ν_1 were respectively the diameter of the pipe and the kinematic viscosity of the air at the upstream pressure tap where the pressure was p_1. Jakob and Kretschmer's discharge coefficient is equivalent to $\alpha \sqrt{\frac{r^2}{r^2-1}}$, and their results are given in the following table, which also includes, for comparison, Hodgson's coefficient 0·61 multiplied by the term $\sqrt{\frac{r^2}{r^2-1}}$. Hodgson's results, according to his experiments, should only hold for values of $\frac{d_2}{d_1}$ less than 0·7, i.e. for values of r greater than 2, but it is interesting to note that the remarkable agreement between his and the German values continues up to a value of $r = 1{\cdot}33$ $\left(\frac{d_2}{d_1} = 0{\cdot}866\right)$, if the coefficient 0·61 is assumed to be valid up to this value. It would therefore appear that a coefficient of 0·61 can be taken with some degree of confidence to apply to sharp-edged orifices of the type shown in Fig. 26 for values of $\frac{p_2}{p_1}$ between 1 and 0·98, and for values of $\frac{d_2}{d_1}$ at least up to 0·7, and possibly up to 0·85.

TABLE II.

$\frac{d_2}{d_1}$	$r = \left(\frac{d_1}{d_2}\right)^2$	Jakob and Kretschmer's Discharge Coefficient.	$0{\cdot}61 \sqrt{\frac{r^2}{r^2-1}}$ Discharge Coefficient Reduced from Hodgson's Value for $\frac{p_2}{p_1}$ nearly Unity and $\frac{d_2}{d_1} < 0{\cdot}7$.
0·387	6·67	0·61	0·62
0·448	5·00	0·62	0·62
0·500	4·00	0·63	0·63
0·548	3·33	0·64	0·64
0·591	2·86	0·65	0·65
0·633	2·50	0·66	0·67
0·671	2·22	0·68	0·68
0·707	2·00	0·70	0·70
0·742	1·82	0·73	0·73
0·775	1·67	0·76	0·76
0·806	1·54	0·80	0·80
0·837	1·43	0·85	0·85
0·866	1·33	0·91	0·92

For other values of $\frac{p_2}{p_1}$ an approximate value of α is given by equation (13). As has already been pointed out, however, most practical cases will come within the conditions where α may be taken as 0·61 without correction.

The Compressibility Correction.—We must consider now the application of the compressibility correction, i.e. the value of C in equation (12), for values of $\frac{p_2}{p_1}$ differing appreciably from unity. The following table gives values of C for air for values of $\frac{p_2}{p_1}$ between 1·0 and 0·80, and of r from 1·4 to 6·0. By plotting the figures given, the value of C within the ranges of $\frac{p_2}{p_1}$ and r stated can be found for any conditions. Cases outside these ranges will seldom occur. It will be seen that C is sensitive to relatively small changes in r when r is small; but that, at a given value of $\frac{p_2}{p_1}$, the variation of C with r becomes progressively smaller as r increases. For example, when $\frac{p_2}{p_1} = 0{\cdot}80$, the value of C changes by a little over 1 per cent. as r increases from 3·0 to 6·0, whereas for the limiting case when r is infinite, which corresponds approximately to the condition of air discharging from a large chamber through a small orifice, the value of C is within about 0·5 per cent. of its value when $r = 6{\cdot}0$. The larger the ratio $\frac{p_2}{p_1}$, the smaller is the variation of C over the range of r.

TABLE III.

r.	$\frac{d_2}{d_1}$.	Values of C when $\frac{p_2}{p_1}$ =									
		0·98.	0·96.	0·94.	0·92.	0·90.	0·88.	0·86.	0·84.	0·82.	0·80.
1·4	0·845	0·975	0·952	0·928	0·901	0·884	0·863	0·841	0·823	0·802	0·783
1·6	0·791	0·980	0·963	0·943	0·925	0·906	0·889	0·871	0·854	0·835	0·819
1·8	0·745	0·982	0·968	0·950	0·934	0·918	0·902	0·886	0·871	0·854	0·838
2·0	0·707	0·984	0·971	0·954	0·940	0·925	0·910	0·894	0·882	0·865	0·850
2·2	0·674	0·985	0·973	0·958	0·943	0·929	0·915	0·901	0·888	0·872	0·857
2·4	0·646	0·986	0·974	0·960	0·946	0·932	0·919	0·904	0·892	0·877	0·863
2·6	0·620	0·986	0·975	0·961	0·948	0·934	0·921	0·908	0·896	0·881	0·867
2·8	0·598	0·987	0·976	0·962	0·949	0·936	0·924	0·910	0·898	0·884	0·870
3·0	0·577	0·987	0·976	0·963	0·951	0·938	0·925	0·912	0·899	0·885	0·872
3·5	0·535	0·988	0·978	0·965	0·952	0·940	0·927	0·915	0·903	0·889	0·876
4·0	0·500	0·988	0·978	0·965	0·954	0·942	0·929	0·917	0·906	0·892	0·879
4·5	0·471	0·988	0·978	0·966	0·954	0·942	0·931	0·919	0·907	0·893	0·881
5·0	0·448	0·988	0·979	0·966	0·955	0·943	0·932	0·919	0·908	0·895	0·882
5·5	0·426	0·988	0·979	0·966	0·956	0·944	0·932	0·920	0·909	0·896	0·883
6·0	0·408	0·988	0·979	0·967	0·956	0·944	0·932	0·920	0·909	0·896	0·884

Some uncertainty arises in the choice of the correct value of C. We have already had occasion to notice that the theoretical equations for the discharge are based on the assumption that the various quantities with suffix 2 relate to the section of minimum area and not to the area of the orifice itself. Now experiments have shown that the downstream pressure, measured at the plane of the orifice, is usually not much different from that at the vena contracta, whereas the area of the vena contracta is, as already remarked, appreciably less than that of the orifice. We should, strictly, in making the compressibility correction, take the value of p_2 and of a_2 at the vena contracta; but no great error is introduced if we take p_2 at the downstream plane of the orifice instead of at the vena contracta. On the other hand, some allowance for the reduction in area is necessary, since the true ratio of areas is not $\frac{a_1}{a_2}$ but $\frac{a_1}{\lambda a_2}$ or $\frac{r}{\lambda}$, where λ is the ratio of the area of the vena contracta to the area of the orifice. Now λ is not readily determinate by experiment, but an approximation to its value can be obtained by the following method.

The assumption is made that the area of the vena contracta is not affected by compressibility, i.e. that the shape of the stream on emerging from the orifice is the same as that for an incompressible fluid. It is unlikely that this assumption is strictly true, but if the value of $\frac{p_2}{p_1}$ is not too small it probably gives sufficient accuracy, since we are seeking a correction factor to C, which itself has the nature of a correction.

On this assumption, therefore, we may revert to the method by which the flow equation for an incompressible fluid was established, and derive an equivalent expression in a slightly different manner. We take λa_2 as the area of the vena contracta, where λ is less than unity, and, if we now take all conditions with suffix 2 as those obtaining at the vena contracta (except p_2, which, as we have seen, may be the value of the pressure at the downstream plane of the orifice), equation (4) becomes

$$q = \delta(\lambda a_2) g \sqrt{\frac{2\rho(p_1 - p_2)}{1 - \frac{\lambda^2 a_2^2}{a_1^2}}}, \qquad (14)$$

where δ is the ratio of the actual velocity through the vena contracta to the theoretical. This ratio will be less than unity on account of the frictional loss through the orifice.

The quantity q as determined from equation (14) is that calculated from the conditions obtaining at the vena contracta,

whereas in (5) it was determined from the conditions at the orifice. Equations (5) and (14) therefore represent the same quantity and hence we may equate their right-hand sides and obtain

$$\delta\lambda a_2\sqrt{\frac{a_1^2}{a_1^2-\lambda^2a_2^2}}=\alpha a_2\sqrt{\frac{a_1^2}{a_1^2-a_2^2}},$$

or $$\frac{\delta^2\lambda^2}{r^2-\lambda^2}=\frac{\alpha^2}{r^2-1}\quad\text{(where } r=\frac{a_1}{a_2}\text{ as before),}$$

from which $$\lambda=\alpha r\sqrt{\frac{1}{\alpha^2+\delta^2(r^2-1)}}$$

Hence $$\frac{r}{\lambda}=\sqrt{1+\frac{\delta^2}{\alpha^2}(r^2-1)}\quad .\quad .\quad .\quad (15)$$

Now the frictional loss through a sharp-edged orifice is known to be small. From experiments with water, the value of δ has been found to be between 0·96 and 0·998.* In making the approximation to $\frac{r}{\lambda}$ by equation (15) a mean value of 0·97 may therefore be taken for δ, and if, further, we take α as 0·61, equation (15) reduces to

$$\frac{r}{\lambda}=\sqrt{2{\cdot}52r^2-1{\cdot}52}.\quad .\quad .\quad .\quad (16)$$

In calculating the value of C, therefore, the quantity $\frac{r}{\lambda}$, as given by (16), should be used instead of r wherever the latter occurs in the formulæ.

It has already been pointed out that the variation of C with r is not great when r exceeds 3. Hence a rapid approximation to $\frac{r}{\lambda}$ may often be made by making use of the fact that the limit to which this ratio tends as r becomes progressively larger is, as shown by equation (15), equal to $\frac{\delta r}{\alpha}$, or 1·59r if $\delta = 0{\cdot}97$ and $\alpha = 0{\cdot}61$. The substitution 1·59r may therefore be made for $\frac{r}{\lambda}$ in calculating C instead of the value given by (16). The value of $\frac{r}{\lambda}$ calculated from this approximate expression when $r = 2$ is 3·18, and from equation (16), 2·92, and on reference to Table III. the difference in C is seen to be negligible. At higher values of r the error is still less, but the approximation should not be used for values of r less than about 1·7.

* *Hydraulics*—Lea, 2nd Edition, p. 57.

Summary of Data for Sharp-Edged Orifices.—We may now summarise the results for sharp-edged orifices of the type shown in Fig. 26 as follows :—

(1) For values of $\frac{d_2}{d_1}$ less than 0·7,* and for values of $\frac{p_2}{p_1}$ greater than 0·98, the value of the discharge coefficient may be taken as 0·61 without correction. If we exclude cases of the flow of compressed air, $\frac{p_2}{p_1}$ will not be less than 0·98 until the pressure drop across the orifice $(p_1 - p_2)$ exceeds about 8 inches of water.

(2) When $\frac{p_2}{p_1}$ is less than 0·98, α is given approximately by equation (13), and this value of α must be multiplied by a compressibility factor C, whose value is given by equation (9) and in Table III.

(3) In calculating C the ratio of areas r must be replaced by $(1{\cdot}59r)$ provided that $\frac{d_2}{d_1}$ is less than 0·77 ($r = 1{\cdot}7$ approximately), otherwise the substitution $\sqrt{2{\cdot}52r^2 - 1{\cdot}52}$ must be employed.

The value 0·61 for the discharge coefficient only holds, within the limits noted above, for orifices of the type illustrated in Fig. 26, in which the upstream edges are sharp and truly square, and bevelled off on the downstream side, and when the pressures are determined at the walls of the pipe in the upstream and downstream planes of the orifice plate. It should also be remembered that the coefficient of discharge will almost certainly depend upon the velocity distribution in the pipe upstream of the orifice. We have already seen that in a given pipe the velocity distribution ultimately assumes a definite form, which is substantially the same for all pipes and does not vary much with rate of flow once the critical velocity is exceeded (see Fig. 18). It is found, however, that the air has to travel along a length of straight pipe measured from the inlet of at least 30 or 40 pipe diameters, before the characteristic distribution is finally assumed. At sections nearer to the inlet, disturbances due to the entry of the air into the pipe are liable to influence the distribution of velocity. This point was no doubt appreciated by Hodgson in his researches, and it is to be presumed that his coefficients relate to orifices placed in the region of what we may term normal distribution, that is to say in straight pipes, reasonably smooth, at the requisite distance from the inlet.

* According to Jakob and Kretschmer this ratio may be as large as 0·85.

It appears, therefore, that orifices placed in regions where the velocity distribution is not normal may have different discharge coefficients, although they are otherwise similar in every respect to orifices having coefficients of 0·61, so that, in addition to the necessity for accurate workmanship in the making of the orifices, care has to be taken that they are installed in suitable lengths of pipe if they are to be used without calibration. For most practical purposes it will be sufficiently accurate to assume that Hodgson's coefficients will hold if the orifice plate is preceded by a straight length of pipe 10 diameters in length. In cases in which the necessary length of straight pipe is not available, or in which some doubt is felt as to the actual distribution of velocity, a preliminary calibration of the orifice should be undertaken. In such circumstances, it may prove advantageous to instal an orifice with slightly rounded edges, which is easier to construct and not so likely to suffer damage as the sharp-edged type, and to locate the pressure taps at any convenient points near to the plate, but not necessarily in the upstream and downstream planes.* A calibration can then be performed in order to determine the coefficient for that particular orifice, as installed. If the pipe is sufficiently large, the quantity of air flowing can be measured by a Pitot tube as already described; otherwise one of the methods for small pipes (see Chapter VIII.) must be employed. At the same time the pressure difference across the orifice and the air temperature in the pipe and the barometric pressure at the time of measurement must also be observed. Equation (9) or (12) for the discharge through the orifice can then be solved for α, by inserting the measured value of Q. If $\frac{p_2}{p_1}$ is less than 0·98, p_1 and p_2 must be measured in order to determine their ratio, and C must be calculated. Initially, before α is known, it will not be possible to determine the value of $\frac{r}{\lambda}$, according to equation (16), which must be used instead of r in calculating C. It will then be necessary to calculate an approximate value of α, using r instead of $\frac{r}{\lambda}$ in evaluating C. From this approximate value of α, a first approximation to $\frac{r}{\lambda}$ can be calculated from equation (16). C can then be re-calculated, using the approximate value of $\frac{r}{\lambda}$ thus determined, and a second approximation to α can then

* It should be remembered, however, that the downstream pressure is a minimum at the vena contracta, so that the pressure difference to be measured will become progressively smaller as the downstream tap is moved further downstream from the vena contracta, until the position of maximum downstream pressure (minimum pressure difference) is reached where the pipe again runs full.

be found. If necessary this procedure can be repeated a stage further, but it will usually be found that the second approximation to α is sufficiently close to the real value.

Orifice Plates in which the Pressure Connections are not at the Upstream and Downstream Planes.—In their Report on Fluid Meters * the Special Research Committee of the American Society of Mechanical Engineers give numerous data compiled from the results of tests on sharp-edged orifices in which the pressure connections were at positions other than at the two planes of the plate. It would seem, however, that more reliance can be placed on Hodgson's experiments than on the others cited in the above-mentioned Report. It may be said, in fact, that Hodgson's results appear to provide the most trustworthy information on sharp-edged orifices at present in existence; but there is still a wide field to be explored before the characteristics of these devices can be regarded as completely elucidated.

Loss in Pressure Due to the Passage of Air through an Orifice Plate.—As we have seen, the static pressure at the downstream face of an orifice plate is considerably less than that in the air upstream of the plate. There is a further slight decrease as the air leaves the orifice, a pressure minimum being reached at the vena contracta at about $\frac{1}{2}$ to 1 pipe diameter

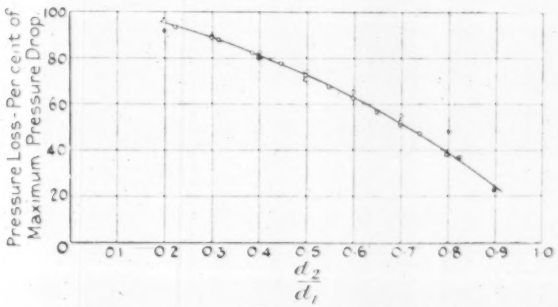

FIG. 27.—Pressure loss due to orifice plate.

from the orifice. This pressure minimum is followed by a gradual recovery of pressure which persists up to a distance of about three to ten or more diameters downstream of the orifice, the actual distance increasing with the ratio r and probably depending also on the rate of flow. At some point, therefore, a pressure maximum is experienced, which corresponds to the position where the jet, which at the vena contracta had a section considerably less than that of the pipe, has expanded once more to the full pipe diameter. After this pressure maximum has been reached the flow proceeds to follow

* Published by the American Society of Mechanical Engineers, New York.

the normal laws of pipe flow, and the pressure falls off gradually on account of the ordinary frictional loss at the walls. The point to be observed is that the static pressure at the downstream point of maximum recovery is considerably less than that upstream of the orifice, and also considerably less than the static pressure that would be experienced at that point if the orifice were removed and the normal frictional pressure drop in a parallel pipe existed between the upstream position and the downstream position corresponding to the point of maximum recovery with the orifice in place. The orifice, in fact, introduces a resistance equal to that of a long length of pipe, and causes a corresponding loss of head or energy in the flow. In other words, a fan delivering a given quantity of air per unit time along a pipe line would take more power if an orifice were introduced into the line and the quantity of air flowing were maintained at its previous value.

Some idea of the pressure loss experienced by air in its passage through an orifice may be gained from Fig. 27 which is taken from the Research Report on Fluid Meters of the American Society of Mechanical Engineers, and represents the mean of the results obtained by a number of workers. The static pressure drop between an upstream point near the orifice and the downstream point of maximum recovery is expressed as a percentage of the pressure difference between the same upstream point and the vena contracta (i.e. the maximum pressure difference across the orifice), and is plotted on a base of $\frac{d_2}{d_1}$. It may be noted that this curve agrees fairly well with similar data given by Hodgson,* when allowance is made for the fact that Hodgson measured his downstream pressure in the plane of the orifice.

* *Proc. Inst. Civil Engineers*, loc. cit., Fig. 18.

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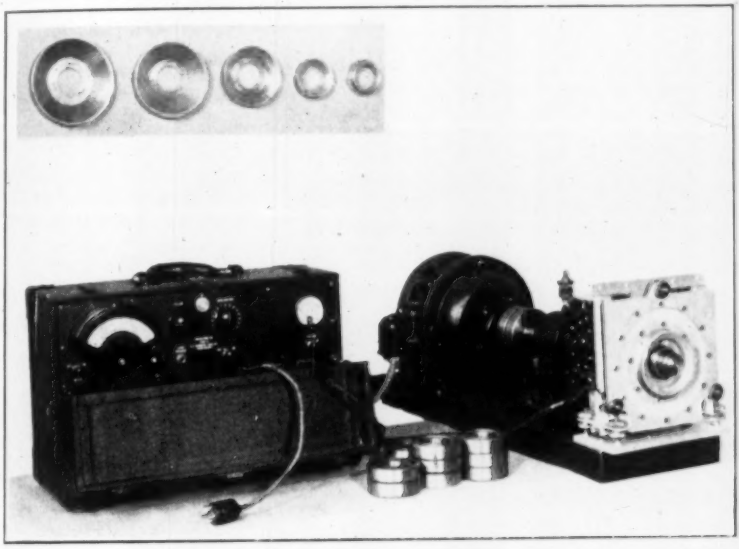
TO IMPROVE the methods of inspecting ball and roller bearings for smooth and quiet operation, the Burgess Bearing Tester has been developed by the C. F. Burgess Laboratories, Inc. and is being marketed by Burgess-Parr Company. This device is an acoustimeter, with which bearings may be definitely separated into as many as 6 different degrees of quality.



Tests have been made which demonstrate that different inspectors at the same or different times can check their sorting only by use of electrical acoustic devices. By the usual methods of testing bearings by ear, inspectors cannot consistently check themselves from time to time, but with the Burgess Bearing Tester consistent results are obtained. In this way, sorting can be made definite, and the hazard of accepting poor bearings or of rejecting good ones is eliminated. Additional advantages are that the sorting can be done anywhere in the factory, thus eliminating the expense of sound proof rooms and hauling costs to and from the inspector, and that highly specialized labor is not required for classifying the bearings. The Burgess Bearing Tester provides the basis for a scientific method for studying bearing design and construction.

The photograph shows the tester in operation. Amplifying adjustments are properly set, the motor and spindle are rotated, and the bearing to be tested is pushed against the pick-up cone. The bearing vibrations are transmitted to the pick-up, are changed into electrical energy, and are

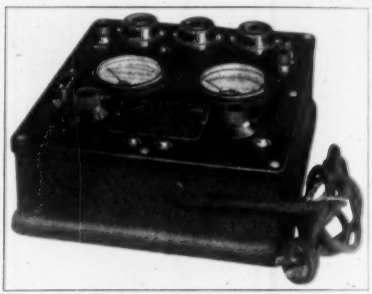
properly filtered so that only those vibrations which are indicative of bearing quality are employed in the amplifying circuit. This filtered and amplified electrical energy is indicated by the deflection of the needle of an electrical meter, and in this way the quantity of undesirable vibrations of each bearing is accurately indicated. The bearing is then reversed, so that it may be tested from both sides, and from the meter readings produced, the bearing is classified.

In adjusting the amplifying circuit, a bearing adopted as excellent is tested, and the zero setting of the meter adjusted so as to produce only a slight deflection. A bearing which is unsatisfactory is tested, and the amplifying adjustments set to give a full scale deflection. The instrument is then ready for use, and by noting the amplitude of the needle deflection, the quality of the bearing is determined. As many as six classifications between excellent and defective can be made in this way.

Counter Tube Checker

(Western Electrical Instrument Corp.)

RADIO dealers fully realize the importance of testing tubes at the time of sale. To more effectively meet this important need the Counter Tube Checker, Model 555, was designed. This tube checker meets all tube checking requirements. It operates direct from any regular 110 volt A. C., 60 cycle lighting circuit. Variations in line voltage from 90 to 130 volts are compensated for by a voltage adjuster mounted directly on the panel.



All A. C. or D. C. tubes can be checked having filament voltages of 1.5, 2, 2.5, 3.3, 5 or 7.5 volts including '80 and '81 types of rectifier tubes. A unique feature of this tester is that both plates of the '80 type rectifier tube can be tested without the use of an adapter. It is only necessary to press a button marked "Full Wave Rect." for second plate after the first plate reading has been made.

To operate Model 555 Tube Checker the following simple procedure is all that is required. Set the pointer to the arrow on the voltage indicator by turning the voltage adjusting dial. Once that has been done it is only necessary to change the setting when a change in line voltage occurs. Set the filament voltage dial to the rated filament voltage of the tube being tested, insert the tube and allow filament to heat—then read on the tube test meter noting the position of the pointer. Next press the button "Press for Grid Test" and obtain a second reading. The difference between the first and second readings is directly proportional to the mutual conductance and the greater this difference the better the tube. When checking power tubes the button marked "High Range" should be pressed while taking both first and second readings.

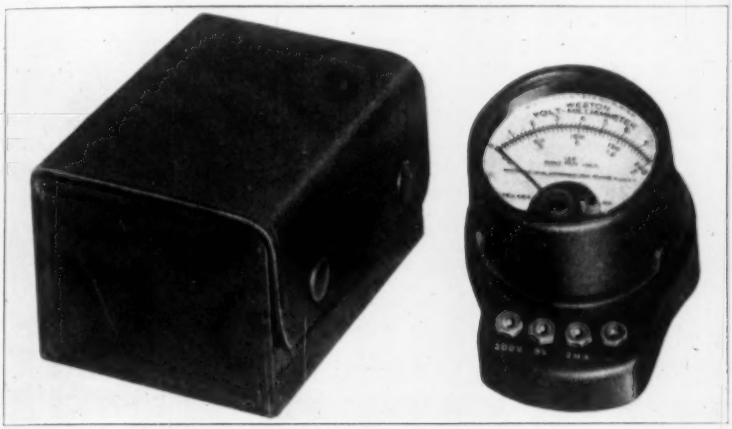
The actual condition of each tube checked is determined by comparing the tube test meter indications with the values for each type tube shown on the Instruction Card. It is important to remember that these values represent average tests on thousands of known good tubes.

Miniature Radio Testing Instruments

(Weston Electrical Instrument Corp.)

THIS instrument, Model 489, is a portable volt-milliammeter with ranges of 200 and 8 volts and 2 milliamperes. Voltage ranges have a sensitivity of 125 ohms/volt so as to indicate the actual operating voltages of the batteries. The meter is supplied with a pair of 30" flexible cables equipped with test prods.

Common faults such as weak or no reception and poor quality are mainly attributable to low battery conditions, loose or broken connections, open coil windings, misallignment of condensers, speaker adjustment and tube failures.



Tests made directly at the tube socket will indicate the conditions of batteries as well as the continuity of circuit. When making these tests turn on the set, remove the tube and insert the cable terminals in the correct jacks of the meter. Then to measure filament voltage insert test prods in socket openings "F to F" using the 8 volt range of the instrument—to measure grid voltage use the same range and insert test prods in socket openings "G to F"—for cathode voltages use either the 200 or 8 volt range and insert prods in socket openings "K to F"—for screen grid voltage use the 200 volt instrument range and insert test prods in socket openings "G to F" and for plate voltage using the same range insert test prods in socket openings "P to F."

Screen Grid or Plate Current can be measured by using the 2 milliampere instrument range by connecting the meter in series with the proper lead to the "B" battery, and inserting one tube at a time.

This instrument is a miniature portable D. C. Volt-Milliammeter having one current and two potential ranges.

It is enclosed in a molded black Bakelite case equipped with pin-jacks for pluging-in instrument connections.

A pair of 30" flexible cables is provided with pin terminals on one end

for inserting into the instrument and prods on the other end for test purposes.

The scale is silver etched figured for all three ranges, 0 to 200 volts, 0 to 8 volts and 0 to 2 milliamperes. The voltage ranges have a resistance of 125 ohms per volt. This miniature instrument has a guaranteed accuracy of 2%. A zero corrector is provided for adjusting the zero position of the pointer. This rugged instrument is very compact, weighs only 11 ounces and is exceptionally handy and dependable in operation.

New Gage for Thin Materials

(B. C. Ames Co.)

The accompanying photograph shows a gage which has been designed for rapidly and accurately measuring thin materials, fabrics, paper, celluloid, films and similar stock. The dial reads direct to .000025" and even closer measurements can be estimated.

Any size contact points can be furnished and the jaws are opened by depressing the lower contact by means of the lever. Releasing the lever brings the lower contact up to a predetermined stop, which on material less than .002" thick gives a zero reading on the dial. On material of greater thickness, the zero reading is obtained by inserting a standard between the contact points, allowing the lower contact point to come against the stop, properly adjusted to bring the hand to zero on the dial.

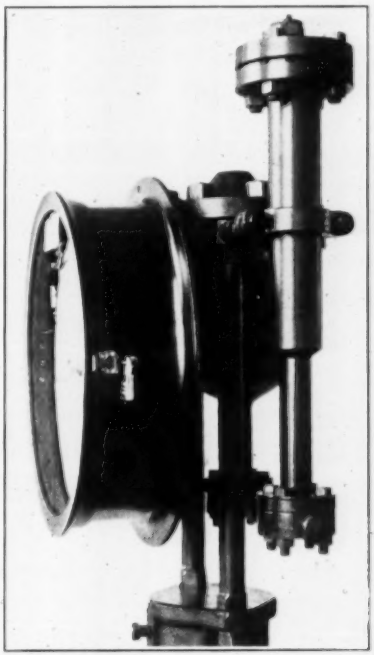
The gage is attractively finished in black crystalline, with all bright parts chromium plated.

The Dash Instrument Engineering Co., San Gabriel, Calif., was organized for the repair, testing and installation of avigation instruments. They have been authorized to service the instruments of Elgin National Co., General Electric Co., Pioneer Instrument Co. and Weston Electrical Instrument Corp.

Two New Flow Instruments for High Pressure Work

THE Foxboro Company has just brought out a new high pressure recording flow meter and flow controller. The new instruments are built for operating pressures of 2,500 lbs. 2 in. They serve as worthy companions to the Foxboro high pressure flow meters and flow controllers for 5,000 lb. pressure applications. (See INSTRUMENTS, January 1930, page 62.)

The illustration shows a single pen 2,500 lb. recording flow meter. If static readings are needed a two-pen instrument with static element is furnished. When total flow readings are desired an integrator can be supplied on the instrument. The integrator gives the flow readings without the use of any multipliers.



The new flow meters and also the new flow controllers can be mounted in place without the use of loading devices. This makes them particularly adaptable to modern field service conditions.

The new meters and controllers retain all the features of Foxboro orifice meters. All parts of the new instruments are specifically designed for high pressure applications. All working parts are drop forgings. The illustration shows clearly their sturdy construction.

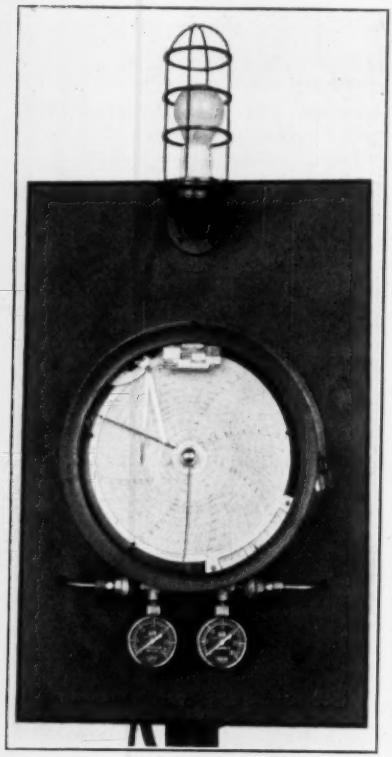
The new instruments have no errors or variables. They possess no unknown quantities—no inherent defects. The field experience gained through use of the first high pressure eters and flow controllers, for 000 lb. pressure applications, makes is possible.

The combination of four factors—accurate coefficients, a differential measuring device that is inherently correct, a simple integrator that can be depended upon, positive control action, and chambers that will withstand high pressures results in high pressure recording flow meters and flow controllers of rugged accuracy.

New Dye Tub Control

(Foxboro Company)

THE new Foxboro Control fits the modern trend in piece dyeing. This controller takes the pre-heated dye water being delivered to the machines, raises it to the exact temperature needed and holds it at this



temperature for a definite time predetermined by the dyer. When the time is up the instrument shuts off the steam and turns on a signal light.

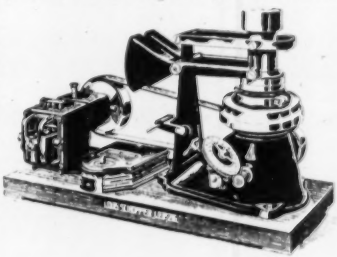
The illustration above shows the complete Foxboro control panel. In addition to the temperature control unit the instrument is equipped with a time scale and a movable index. The operator sets the time index to the point representing the total time for the dye operation. At the end of the period the control shuts off and the signal, shown in the picture, lights. If the operator finds that the batch requires longer time he merely sets the index for the increase in time and the steam is automatically turned on, the light extinguished and the process continues until the end of the period. The operator always has before him, as a guide, a complete record of each operation in time and temperature. The possibilities for matching shades with this new control system are unlimited.

The Foxboro control unit is furnished complete as shown mounted on an ebony asbestos panel with lamp bracket and accessories. It can be easily mounted from the floor, on a machine or post, depending on the convenience for the particular installation. There are no adjustable cams in this instrument.

Tissue Abrasion Tester

(H. Z. Schniewind)

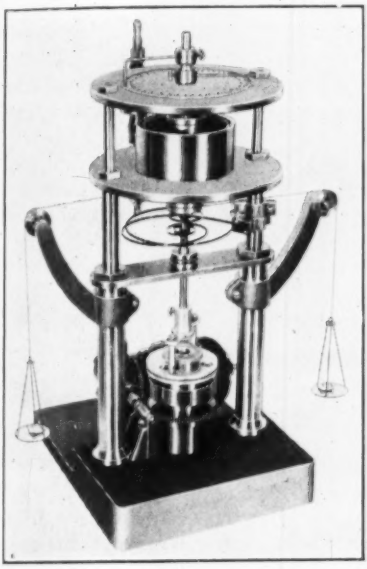
THIS new machine is designed for testing tissues and fabrics for wear and tear. The test-sample is fastened upon a metal base and subjected to abrasion in different directions and, with interruptions, on different spots so that the fibres may rise again from time to time. The sample is subjected to a combined rotary and rolling motion, whereby it is rubbed against a rubbing plate under adjustable load. The abrasion is measured by determining after a certain number of revolutions either the loss of weight or the increase of air permeability.



The Herschel Oiliness Machine

(American Instrument Co.)

SEVERAL attempts have been made to build dependable friction machines with only moderate success. Perhaps the simplest machine is the block sliding down an inclined plane. As the angle of the plane is slowly increased a point is reached at which the block begins to slide and the tangent of the angle of inclination is the coefficient of friction. The criticism of this machine is that it is practically impossible to tell just when the block begins to slide, and it is almost as difficult to reproduce the degree of smoothness on the bearing surfaces, as they wear.



Other machines using flat pegs as one member of the bearing couple, show a difference in coefficient of friction with pressure.

In order to qualify as a successful machine for determining friction such a machine must be free from both the above criticisms and also must be free from the effects of temperature and vibration. The polish of the bearing surfaces must be readily and exactly reproduced to make readings comparable.

The Herschel Oiliness Machine consists essentially of a motor driven disk carrying a specimen of metal to be tested upon which rests a tripod carrying 3 commercial $\frac{1}{2}''$ diameter hardened steel balls fixed between two plates. As the disk rotates the tripod tends to follow its motion being resisted by 2 spiral springs. The greater the frictional force between the specimen and the balls the greater the tendency for the tripod to rotate and increase the spring tension. When the spring tension equals the frictional force between the tripod and specimen the tripod begins to slip and continues to slip as long as the machine runs.

By definition the coefficient of friction equals the force necessary to move a body divided by the weight of the body. In this case the weight of the tripod is easily determined with a balance. The actual weight is approximately 125 grams. The force exerted by friction between the tripod and specimen is measured by the degree to which the springs wind before slipping takes place. The springs are carefully calibrated by placing known weights on the two scale pans shown in the cut and noting the deflection of the pointer over a graduated scale at the top of the instrument. Thus if a total weight of 25 grams causes a deflection of the pointer of 150°, the spring constant is 6, or in other words the springs exert a force of 6 grams per degree deflection of the pointer.

By properly controlling the physical dimensions of the instrument it is made to read coefficient of friction directly without the use of charts, tables, or conversion factors.

The moving mechanism rests on a sapphire jewel and is guided at the top by a hardened steel pivot riding in a bronze sleeve. By this construction the friction in the mechanism becomes negligible. The instrument carries a damping chamber to eliminate the minor oscillations of the pointer.

The motor is mounted on soft rubber cushions and the drive is through a soft rubber belt. Thus no motor vibrations can be transmitted to the measuring mechanism. The whole instrument rests on another soft rubber cushion to prevent building vibrations affecting the readings.

The instrument is of value in the investigation of oiliness where bearing pressures are high and speeds low and where incomplete film lubrication exists such as in gears transmitting heavy loads.

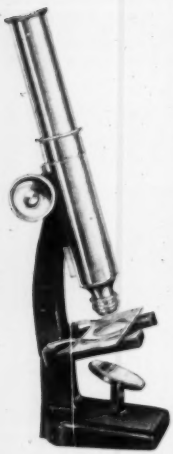
Unlike most friction machines the bearing surfaces in this machine are readily renewed. The balls may be rotated to a new position by merely loosening the two clamping plates with the fingers, turning the balls to a new position and again clamping the plates. The bearing metal specimens are renewed by rubbing them on a piece of broadcloth covered with a paste made of chromium oxide and water.

Very small differences in the coefficient of friction may be obtained with this instrument. For instance, a few drops of lard oil in several ounces of lubricating oil is readily detected. The difference in various bearing metals with the same lubricant can also be detected.

Specimens of leaded bronze and white metal are ordinarly furnished with the machine and the manufacturers are prepared to supply other alloys where the purchaser furnishes the blanks from which they may be machined.

New Gem Microscope

(Bausch & Lomb Optical Co.)



TODAY the microscope opens up new worlds which are as rich in discoveries as those brought to light by explorers of unknown regions in times past. This spirit of adventure still lives in the youth of today and can be satisfied in the school room or at home through the medium of this instrument of optical science.

The New Gem Microscope offers a wonderful opportunity to explore the unknown mysteries of a drop of water, a fly's wing, or countless other minute organisms. The New Gem is not a toy, but a scientifically constructed instrument, and is produced with the same attention to correct detail that characterizes the entire B & L line of microscope and other instruments for laboratory research work.

The draw tube and double objective lens gives the New Gem Microscope a range of magnifying powers of from 75 to 300 diameters. There is a rack and pinion adjustment for focusing, and the base is angled to facilitate manipulation and may be removed for observation of objects too large for the stage.

Time Cycle Contactors

(*Automatic Temperature Control Co.*)

CONTACTORS to enable carrying out a program of operations on a time cycle basis are daily coming into greater use for such work as the automatic operation of furnace doors, automatically advancing the load in a continuous type furnace, automatically timing material being heated or electro-plated, automatic lubrication, automatic operation of hydraulic presses for tempering saws for plastic molding of bakelite, hard rubber, etc.

A few of the time cycle contactors developed by this Company, to meet this varied demand are briefly described below and may be broadly classified under two general groups, viz.:

1. Cycle Repeating Contactors, designed to periodically repeat the cycle so long as the line switch is closed.
2. Cycle Stop Contactors, designed to start from a push button switch, run the time cycle set and stop until the starting switch is again actuated.

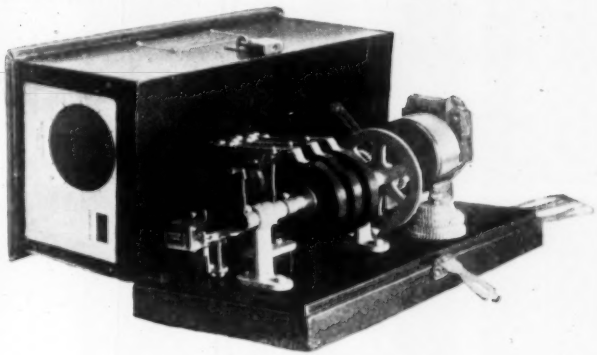


Fig. 1

Fig. 1 shows a Cycle Stop Type Contactor designed to handle three contacts per cycle in desired sequence. Accurate timing and the necessary power for operation is obtained from a small synchronous motor, geared to desired time of cycle. Change gears permit altering time of cycle. One cam is pinned to the cam shaft, but the others are held in spring tension and are adjustable in relation to each other within the time of the cycle. Provision is made for shortening or lengthening the time of contact per cycle, and where necessary contacts can be provided of a type to quickly make and also quickly break their circuit. Progress of the cycle is shown by an indicator arm which travels around a graduated dial marked on a glass in one end of the instrument case. The number of operations in a given time may be readily noted as a totaling counter is tripped each cycle. Units of this type have been built with eleven contact discs and with a cycle of 96 hours, while others have been built with a cycle of only a few seconds.

Fig. 2 shows a Cycle Stop Type Contactor which does not require change gears to alter the time of cycle, this change being easily and quickly made by means of an adjusting knob outside of the instrument case.

The zero adjusting screw permits accurately setting the lower contact while the adjusting knob mentioned above is used to set the upper contact for any desired elapsed time within the dial range of the unit.

Motive power and means for accurate timing is obtained from a small double field synchronous motor, which moves the elapsed time contact arm clock-wise or counter-clockwise, depending on which of its field coils are energized. This unit is built in both the Cycle Stop and the Cycle Repeat-

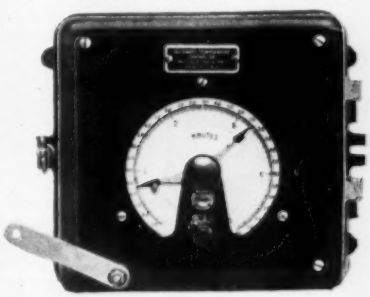


Fig. 2

ing types. The Cycle Stop Type has a reversing switch mounted on the instrument case but where desired, this switch can be located at a distant point.

Note the extension lever at lower left hand corner which is designed for operation of the reversing switch. This lever is normally held in a raised position by means of a spring, this throwing the motor line switch to "off" position. Placing the work in position for treatment mechanically pulls down the lever arm and throws the motor line switch to "on" position, thus energizing one winding of the motor, so that elapsed time contact arm starting from zero, travels clockwise for the time cycle set, upon completion of which, contact is made to operate signal, or where desired, a motor operated controller. Where motor controller is used it can be arranged to automatically remove the work at the end of the cycle and in so doing the lever arm is pulled up by the spring, thus throwing the motor line switch to "off" position. When the next load of work is placed in position, the lever arm is again pulled down throwing the line switch to "on" position, but this time energizing the other winding of the motor, so that the elapsed time arm travels counter clockwise for the same time period, making contact at the zero position of the scale and repeating the signal or the automatic removal of the work.

The table below gives standard full scale dial ranges for this type unit, and the value per scale division.

FULL SCALE RANGE OF DIAL	VALUE PER SCALE DIVISION
1 Minute	1 Second
2 Minutes	1 "
5 "	1 "
10 "	2 Seconds
15 "	3 "
20 "	4 "
30 "	6 "
40 "	8 "
60 "	12 "
120 "	30 "

It is possible to set the high contact arm for any desired elapsed time within full scale range of the dial and this setting can be made *to a scale division or closer*. The elapsed time arm travels with equal accuracy either clockwise or counter-clockwise. These units will be found sturdy in construction, dependable in action, and accurate as to timing.

Fig. 3 shows a timing contactor of the Cycle Stop Type which was designed for a tunnel kiln manufacturer to gradually advance loaded cars of work through a kiln by governing the speed of a hydraulic ram under 3000 pounds pressure. Due to the possibility of "wire drawing" the valve parts at this pressure it was not desirable to throttle the water to the ram in order to take 3 1/2 hours for full ram stroke of 91 inches, hence it was decided to operate a two position motor valve in by-pass line around the ram, this valve to be opened and closed by means of contacts carried by the timing unit.

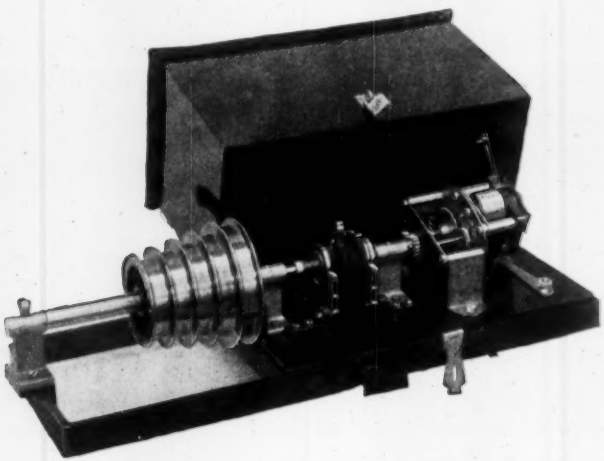


Fig. 3

Referring to Fig. 3, the shaft at right end is driven by a small synchronous motor geared for desired R.P.M. and carries opening and closing contacts. The shaft at left end carries the

common contact and is rotated at speed the ram is travelling by means of a cord attached to the ram and passed over a cone of the step cone pulley, the pulley cone being selected according to the speed desired. In this instance the different cones reduced the ram speed in 15 minute steps from a maximum of 3½ hours.

Arrangements were made that the water supply to the ram could be adjusted so that when valve in by-pass was closed the ram traveled slightly faster than desired and when open, slightly slower than desired. With the ram travelling faster than desired, the common contact on the step cone pulley shaft overtook contact on the motor driven shaft, and actuated the controller to open valve in the by-pass line tending to slow down the ram speed. This permitted the motor driven shaft to operate faster than the step cone pulley shaft, so that the opposite contact was shortly made, thus closing valve in the by-pass line, and in this way keeping the ram advancing at the desired speed.

On small units satisfactory operation was obtained and less equipment required by directly operating the motor driven pump from these contacts, thus eliminating the motor control valve in by-pass lines.

Analyzer for Sound Picture Installations

THE Jewell Electrical Instrument Company has recently developed a compact analyzer for checking sound picture installations. The analyzer consists of four instruments mounted in a sturdy case built to stand the severe usage of service work.

The analyzer has a direct current meter with ranges of 15-150-750 volts, 7.5-75 amperes, 1.5-15-150 milliamperes; an A. C. meter with 4-8-125-250 volt ranges; a thermocouple galvanometer with scale reading 0 to 100, 4½ ohms resistance, 115 milliamperes full scale; and a Jewell Pattern 149 Galvanometer reading 15-150 microamperes.

This carefully designed analyzer gives all filament, control grid, screen grid, and plate readings. Means for making complete tube tests, using the change in grid bias method and means for output measurements of both volume and quality, using variable pitch constant frequency records or films are provided. A feature of this analyzer is that it provides means for measuring photo-electric cell current on a microammeter with ranges of 15 and 150 microamperes.

The analyzer also provides means for measuring continuity and resistance and phasing dynamic speakers. A complete set of binding posts make all meter ranges available for testing independent of the analyzer.

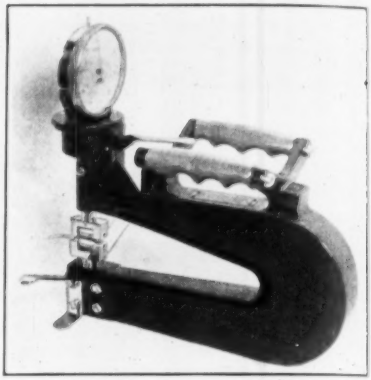
The use of a four-pole, twelve-position switch for pre-selecting the circuit and push buttons for operating the circuit makes operation of the analyzer simple, rapid and safe.

The analyzer is furnished complete with adapters and test leads, place for which is provided in the case.

Gurley Running Sheet Micrometer

(W. & L. E. Gurley)

THE Gurley Running Sheet Micrometer is a simple, accurate device for measuring the thickness of the sheet of paper while it is on the paper machine. The measurement can be made within 8″ from the edge, while the paper is passing between the rollers of the micrometer.



The instrument is made of Lynite, light in weight, strong and rigid. A shell which surrounds the micrometer frame provides protection against warping due to temperature changes, and supports it when lifted. Accurate, perfectly round, crowned rollers replace the usual micrometer anvil, offering little resistance to the passage of the paper. Readings on the dial may be taken to half-thousandths of an inch, or estimated finer.

The Gurley Running Sheet Micrometer is a practical, substantially constructed instrument, for everyday use in the mill. Besides measuring the running sheet, it can be used as a bench micrometer.

New Three Position Pilot Switch

(Cutler-Hammer, Inc.)

MOTOR driven pumps, compressors, and similar machines which are controlled by an automatic pilot device such as a float switch, pressure switch, time clock, etc., often require some means of starting and stopping the motor manually. This can be accomplished by the new three-position pilot switch. The operating lever can be placed in either the "automatic," "off" or "manual" position. When turned to "automatic," the automatic pilot device is in circuit and normal, automatic operation is obtained. With the lever in the "off" position, the pilot circuit is opened and the motor cannot be started from any other control point. Turning the lever to the "manual" position closes the control circuit direct and the motor will run continuously regardless of any other control devices as long as there is operating voltage on the line. The construction is extremely simple. It consists of a two button push-button switch inside the case, the buttons of which are operated by a cam attached to the operating lever. The lever will remain in any one of the three positions.

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TEMPERATURE RECORDERS. Leaflets cover the application of temperature recorders in heating and ventilating; oil refineries; gas works and for carburizing. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

ELECTRIC INSTRUMENTS. Supplement 2 to Bulletin 100 describes the type PD portable pocket volt-ammeter and type HTD headlight tester. Roller-Smith Co., 233 Broadway, New York, N. Y.

REMOTE MANUAL CONTROL SYSTEM. The de Florez remote manual control system is described in Bulletin 7520. This system operates through an application of Selsyn motors. 12 Pages. Brown Instrument Company, 4482 Wayne Street, Philadelphia, Pa.

CONTROLLED VALVES. 36 pages. Bulletin 167 gives engineering data on the Foxboro V-port controlled valves. Foxboro Company, Foxboro, Mass.

HEATED PLATENS. Leaflet TB-24 is a reprint from Engineers and Engineering describing electrically heated platens. Harold E. Trent Co., 439 N. 12 Street, Philadelphia, Pa.

BLOWERS. Bulletin-23-B2 and Bulletin-22-B2 covers Roots roller bearing blowers for Standard and Heavy duty. P. H. & F. M. Roots Co., Connersville, Ind.

DENSOMETER. Bulletin 1410 describes the Densometer, an instrument for measuring the compactness of the fibre structure of various kinds of paper. W. & L. E. Gurley, Troy, N. Y.

INSTRUMENTS FOR ELECTRICAL MEASUREMENTS AT COMMUNICATION FREQUENCIES. Catalog F is a new general catalogue superseding all previous issues. General Radio Company, Cambridge A, Mass.

POSSITIVE DISPLACEMENT METERS. Handbook E-4, 1930 entitled Measurement by Displacement Meters is published by the American Meter Company. Price $1.00. This book covers the methods of testing, maintaining, and repairing large meters. It includes data related to all sizes of positive displacement meters and other material such as appropriate data on the physical properties of gases.

GENERAL PYROMETER CATALOGUE. Loose leaf catalogue covering pyrometers and pyrometer accessories. Claud S. Gordon Company, 708 W. Madison St., Chicago, Ill.

OPTICAL GAGE FOR RODS. Reprint from Machinery describes an optical gaging machine for xylonite rods. Adam Hilger, Ltd., 24 Rochester Place, London, N. W. 1, England.

MERCURY RELAY. Bulletin gives sketches showing 9 hook-ups illustrating the application of the Amino super-sensitive mercury relay. American Instrument Co., 774 Girard St., N. W., Washington, D. C.

WATER WORKS JOURNAL. The July issue of this publication contains the following: Water Mergers and the Public Convenience; Water Supply of San Francisco; and New Haven Water Supply. Pittsburgh Equitable Meter Co., 400 Lexington Ave., Pittsburgh, Pa.

RELAYS. Leaflet 20485 covers the new M-type Auxiliary relays for a-c. or d-c. circuits; in addition it contains a description of the construction, application, and operation of the relays. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

DIRECT READING HUMIDITY RECORDER. Bulletin 880, 1930, describes the L & N humidity recorder. It also has a discussion of the theory of the humidity recorder. Leeds & Northrup Company, 4901 Stenton Ave., Philadelphia, Pa.

TYCOS-ROCHESTER. The July issue of the Tycos-Rochester contains the following: Tornados; What a Tornado Looks Like; Tornados Baffle Science; Government Seeks "Lowest" Temperature; When Lightening Flashes; Sea Going Weather Maps; Sunshine and What It Means to Us; When the Weather Station Goes Aloft; and a number of other articles. Taylor Instrument Companies, Rochester, N. Y.

PYROVISOR-A NEW POCKET PYROMETER. 4-page leaflet illustrates and describes this optical pyrometer. American Demag Corporation, 310 South Michigan Ave., Chicago, Ill.

SPECTROSCOPIC INVESTIGATION. Reprint entitled "Spectroscopic Investigation of the Mineral Constituents of Textiles." Adam Hilger, 24 Rochester Place, London, England.

MINIATURE RADIO TESTING INSTRUMENTS. Leaflet describes the Weston Model 489. Weston Electrical Instrument Corporation, Newark, N. J.

SPRING TESTING MACHINES. Leaflet illustrates the Elasticometer spring testing machines for tension and compression tests. Coats Machine Tool Co., Inc., 110 West 40th Street, New York, N. Y.

GAS SERVICE JOURNAL. The July issue contains the following: Natural Gas-Industrial Fuel's "Dark Horse;" Pioneering Natural Gas Sales in Pittsburgh, Pa.; and Better Methods of Selling Conversion House Heating Equipment. Pittsburgh Equitable Meter Co., 400 Lexington Ave., Pittsburgh, Pa.

INSTRUMENTS FOR THE PAPER AND PULP INDUSTRY. General catalogue of instruments covering temperature and pressure regulators, recorders and indicating instruments, pyrometers, level and vacuum gages, hygrometers, etc. Several recently developed applications are included. Taylor Instrument Companies, Rochester, N. Y.

THERMOMETERS. Bound catalogue 9½ x 13 inches, 124 pages. Illustrates complete line of liquid in glass thermometers. Three languages: German, French and English. Dr. Siebert & Kuehn, Hermannstrasse, Kassel, Germany.

MOTORS. Bulletin 1002-B covers series intermittent service motors with and without speed reducers. Includes a number of applications to instruments. Bodine Electric Company, Oakley Blvd. & Ohio Street, Chicago, Ill.

RADIO SET TESTER AND TUBE CHECKER. D. S. 565 describes the Model 565 radio set tester. Weston Electrical Instrument Corporation, Newark, N. J.

CURRENT AND VOLTAGE RELAYS. Leaflet 20460 describes the types SC and SC-1 current relays and type SV voltage relay. The leaflet presents application, construction, and operating data. Westinghouse Electric & Mfg. Co., East Pittsburgh, Pa.

RESISTANCE THERMOMETERS. Catalog No. 80, 1930 is a revised edition of the previous issue. It treats in detail of L & N resistance thermometers for controlling, recording and indicating temperatures. Considerable space is devoted to heating and ventilating applications, applications in refrigeration and chemical plants, in gas-making and other comparatively low temperature applications. Leeds & Northrup Company, 4901 Stenton Ave., Philadelphia, Pa.

VOLT-OHMETER. Circular GG-564 describes the Model 564 radio instrument for voltage and resistance measurements and for checking continuity of circuit. Weston Electrical Instrument Corp., Newark, N. J.

CYCLE SIGNAL-GRAPH. Bulletin 11 describes the cycle signal-graph for accurate timing and recording of plastic cures. Prodifction Meter Service Corporation, 1315 South Wabash Ave., Chicago, Ill.

AUTOMATIC CONTROL DATA SHEETS. New data sheets have been issued for the Motor Control Section and the Valve Section of the loose leaf catalogue of the Automatic Temperature Control Co., Inc., 34 East Logan Street, Philadelphia, Pa.

AUTOMATICALLY CONTROLLING ACID EFFLUENTS. Reprint of an article of the same title appearing in Chemical & Metallurgical Engineering. Author tells how automatic control of the strength of an acid effluent has cut the consumption of soda ash from 600 lbs. to 20 lbs. a day. Leeds & Northrup Co., 4901 Stenton Ave., Philadelphia, Pa.

COUNTER TUBE CHECKER. Circular 11 illustrates the model 555 counter radio tube checker. Weston Electrical Instrument Corporation, Newark, N. J.

CURRENT METER. Price List 172 contains information and prices on the Ott Meter V. The leaflet is printed in English. A. Ott, Kempten, Bavaria, Germany.

TELESCOPE SUPPORT. Leaflet gives illustrations and prices of telescope supports. Gaertner Scientific Corporation, 1201 Wrightwood Ave., Chicago, Ill.

GRAPHIC INSTRUMENTS. Bulletin No. 730 gives examples of savings made with graphic instruments, in a flour mill and a lumber mill. Easterline-Angus Company, Indianapolis.

RESISTANCE METER. Leaflet illustrates the model 506 resistance meter. Weston Electrical Instrument Corp., Newark, N. J.

BAKELITE REVIEW. The July 1930 issue the application of Bakelite to an instrument for measuring air temperature manufactured by the Moto Meter Co., Inc. Bakelit Corporation, 247 Park Ave., New York, N. Y.

ELECTRIC MAGNETIC COUNTER. Leaflet illustrates electric magnetic counter with switch. Production Meter Service Corp., 1315 South Wabash Ave., Chicago, Ill.

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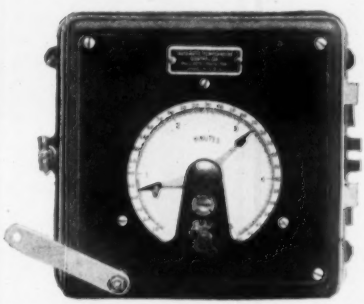

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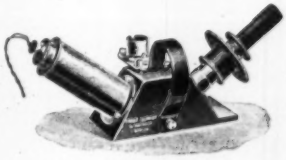

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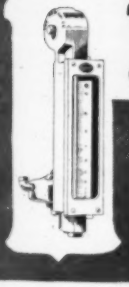

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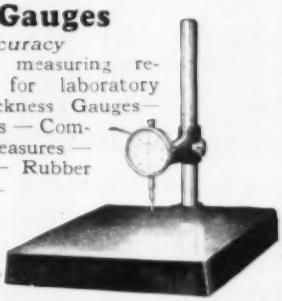

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THE HANDBOOK OF INDUSTRIAL INSTRUMENTS

M. F. BÉHAR, INSTRUMENTS, Vol. 3, No. 9, September, 1930 pages 549-576, 8 figs.

Chapter IX. Industrial Humidity Instruments. This instalment includes: general data and summarized importance with regard to materials, importance with regard to comfort and health, and the measurement of humidity.

MEASUREMENTS—INDUSTRIAL AND SCIENTIFIC

DR. WALTER BLOCK, INSTRUMENTS, Vol. 3 No. 9, September 1930, pages 577-590, 2 figs.

Chapter VII. Measurement by methods other than the use of planimeters is briefly discussed. The theory of the planimeter is covered.

MEASUREMENT OF AIR FLOW

E. OWER, INSTRUMENTS, Vol. 3, No. 9, September, 1930 pages 581-590.

Chapter VI. (cont'd). This instalment covers coefficients of orifices; compressibility correction; summary of data for a sharp-edged orifices; orifice plates in which the pressure connections are not at the upstream and downstream planes; loss in pressure due to the passage of air through an orifice plate.

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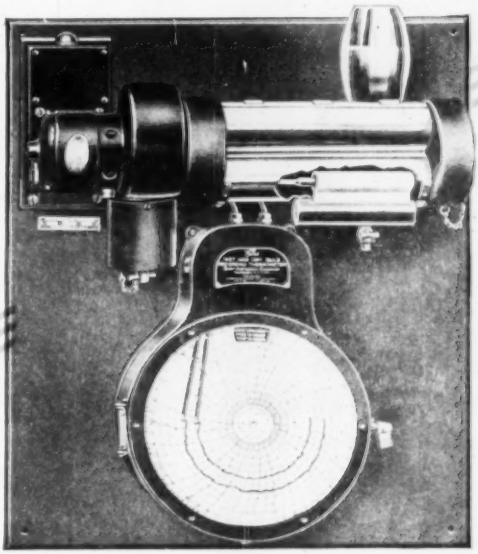

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